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VISCOSITY MEASUREMENTS OF POTENTIAL HIGH DENSITY HYDROCARBON FU--ETC(U)

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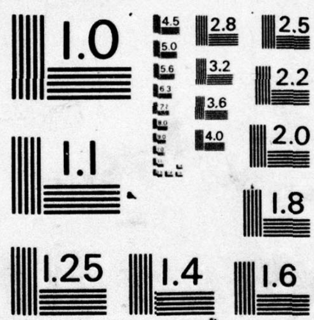

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VISCOSITY MEASUREMENTS OF POTENTIAL HIGH DENSITY HYDROCARBON FUEL BLENDS

FUELS BRANCH
FUELS AND LUBRICATION DIVISION

JUNE 1976

TECHNICAL REPORT AFAPL-TR-76-17
FINAL REPORT 1 FEBRUARY 1973 - 30 JUNE 1975

AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. REPORT NUMBER: AFAPL-TR-76-17

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

9 Final rept. Dec 73 - Dec 74,

4. TITLE (and Subtitle)

6 Viscosity Measurements of Potential High Density Hydrocarbon Fuel Blends.

5. TYPE OF REPORT & PERIOD COVERED: Final Report, December 1973 to December 1974

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10 Herbert R. Lander, Jr.
Alfred E. Strouse

8. CONTRACT OR GRANT NUMBER(s)

11 Jun 76

12 134p.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Air Force Aero Propulsion Laboratory
Fuels Branch (SFF)
Wright-Patterson AFB, Ohio 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 30480547

11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Aero Propulsion Laboratory
Fuels Branch (SFF
Wright-Patterson AFB, Ohio 45433

12. REPORT DATE: June 1976

13. NUMBER OF PAGES: 125

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

16 3048 17 05

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

RJ-5	Fuels
Shelldyne-H	Missiles
Viscosity	High Density Fuel Blends
Weissenberg Rheogoniometer	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The principal problems associated with the use of RJ-5 (Shelldyne-H) as a missile fuel is its high viscosity, particularly at 0°F and below. Chemically, this material can be described as the hydrogenated dimer of norbornadiene (HNBD).

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

011570

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Using the Model 17 Weissenberg Rheogoniometer, the viscosity of pure RJ-5 and blends of RJ-5 and other hydrocarbons was determined over a temperature range from -65°F to +70°F. The hydrocarbons evaluated as viscosity improvers when added to Shelldyne-H include toluene, JP-4, methylcyclohexane, tetralin, decalin, RJ-4 (tetrahydro-methylcyclopentadiene dimer) and isobutylbenzene. The concentrations studied were 5, 10, 25, 35 and 50 weight percent diluent in RJ-5.

Toluene blends were found to be the most effective in reducing low viscosity while retaining volumetric heating values at significantly high levels.

It is concluded that considerable progress is possible in the high density missile fuel area through the blending of hydrocarbon components. Present high density fuels, such as RJ-5 can be tailored to yield fuels with properties which are more adaptable to suitable system designs for low temperature application and yet have significantly more volumetric energy (higher density) than conventional hydrocarbon fuels.

FOREWORD

This report contains the results of an effort to alleviate the high viscosity of RJ-5 (Shelldyne-H®) at low temperatures by means of various hydrocarbon diluents. The in-house research was performed in the Fuels Branch of the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under Project 3048, Task 304805, and Work Unit 30480547. The effort was conducted by Mr. Herbert R. Lander, Jr., of AFAPL/SFF and Mr. Alfred E. Strouse of AFAPL/TFF during the period of 1 February 1973 to 30 June 1975.

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SECTION I
INTRODUCTION

The principle problem associated with the use of Shelldyne-H® (RJ-5) as a missile fuel is its high viscosity, particularly at 0°F and below*. The viscosity of this potential fuel increases more than two orders of magnitude between 0°F and -65°F. The steepness of the semi-logarithmic plot of viscosity as a function of temperature is shown in Figure 1, where the viscosity of Shelldyne-H® is plotted versus temperature. At -65°F, the viscosity of the fuel is increasing at approximately 3000 centipoise per °F. These data were obtained on the cone and plate Weissenberg Rheogoniometer, which will be discussed later in this report.

Chemically, Shelldyne-H® can be succinctly described as a mixture of the hydrogenated dimers of norbornadiene (HNBD dimers). This material has been produced in batch quantities by Shell Development Company, formerly of Emeryville, California, to meet the RJ-5 specification. The chemical and physical requirements of this tentative specification are outlined in Table 1. The properties which best differentiate this fuel from others is the high density (specific gravity is 1.08) and its extremely high viscosity, particularly at lower temperatures. All other properties are quite similar to those of most other aircraft and missile hydrocarbon fuels. Of major concern to the designer is relief of some of the low temperature problems associated with using Shelldyne-H®. These points will be discussed in later sections.

* References (1,2,3,24,25,30)

FIGURE 1. Viscosity of Shelldyne-H® (HNBD Dimer) As a Function of Temperature.

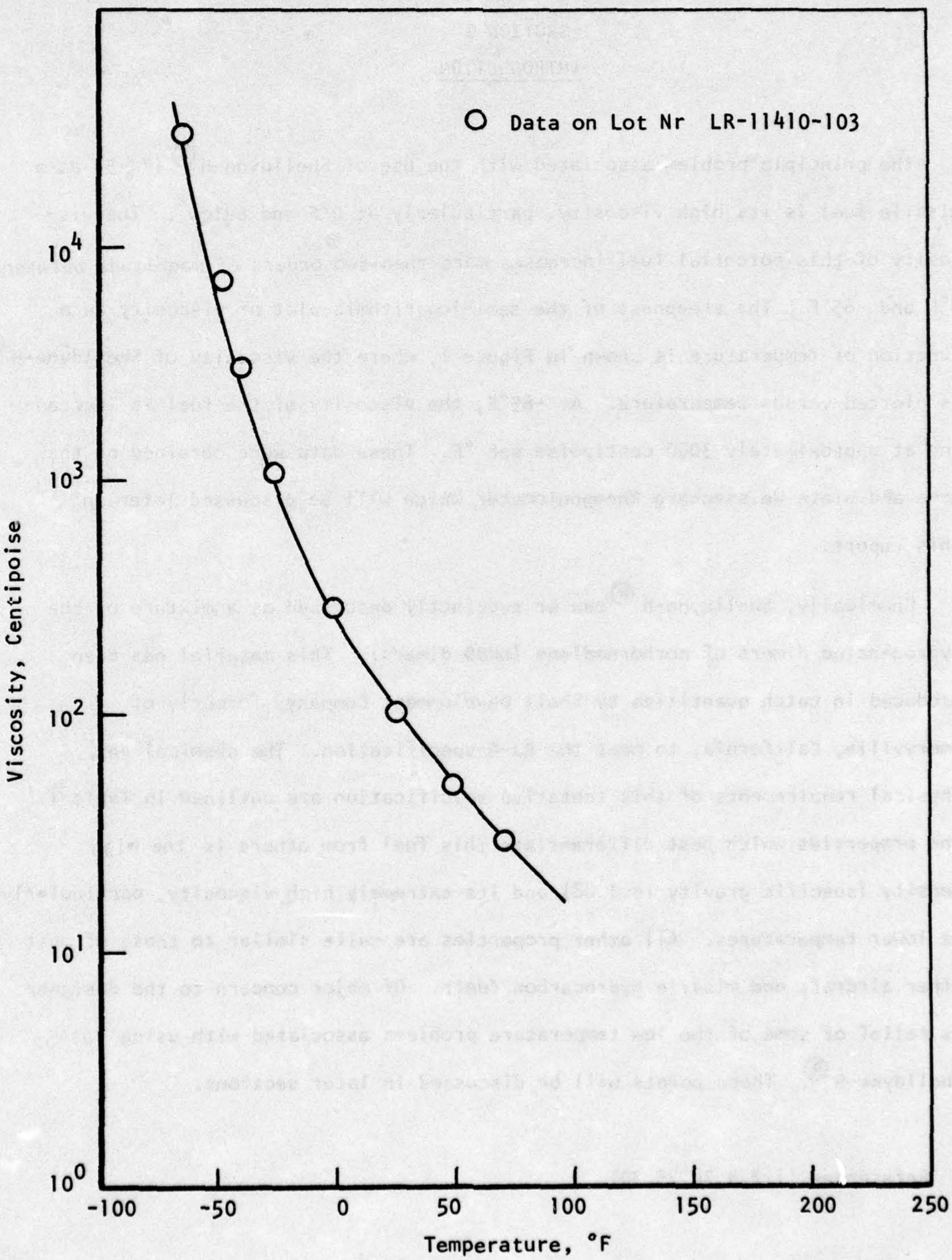


TABLE I

PROPOSED MILITARY SPECIFICATION FOR RJ-5

Requirements	Limits	Test Method ASTM Standard
Distillation Temperature, °F (°C), Min.	470 (243.3)	D86
Initial boiling point		
10 percent point		
20 percent point		
50 percent point		
90 percent point		
End Point, °F (°C), Max	525 (273.9)	
Distillation Residue, Volume %, Max	1.5	
Distillation Loss, Volume %, Max	1.5	
Gravity at 60°F API Max (Sp. Gr. Min)	-0.5 (1.08)	D287
Existent Gum, Mg/100 Ml, Max	7.0	D381
Potential Residue, 16 Hrs Aging, Mg/100 Ml, Max	14.0	D873
Sulphur, Total, Weight Percent, Max	0.05	D1266
Mercaptan Sulphur, Weight Percent, Max	0.001	D1219 or D1323
Pour Point, °F, Max	-65	D97
Heating Value		
Net heat of combustion, Btu/lb, min	17,750	D2382
Net heat of combustion, Btu/gal, min	160,000	
Viscosity, Centistokes, Max		
at -65°F	20,000	
at -30°F	1,400	
at 100°F	15	
Aromatics, Volume Percent, Max	1.0	D1319
Olefins, Volume Percent, Max	1.0	D1319
Flash Point, °F, Min	150	D93
Copper Strip Corrosion, ASTM, Max	No. 1	D130
Thermal Stability		
Change in pressure drop in 5 hrs, in Hg, max	3	D1660
Preheater deposit code, max	2	
Particulate Matter		
Mg/Liter, max F.O.B. origin deliveries	1.0	D2276
Mg/Liter, Max F.O.B. destination deliveries	2.0	
Fuel System Icing Inhibitor		
Volume percent, min	0.10	
Volume percent, max	0.15	
Bromine number, max	1.0	D1159

SECTION II
STATEMENT OF THE PROBLEM

In the short space of one decade, the status of the hydrocarbon fuel known as Shelldyne-H® has risen from a laboratory curiosity to the baseline fuel for the Advanced Strategic Air Launched Missile (ASALM). Volume limited strategic cruise missiles of this type must use denser fuels (or more energy per given volume) if they are to attain greater range. Projected performance requirements of these systems put a high premium on range, time-to-target and packaging. When applied in combination, these factors tend to favor air-breathing engines for non-ballistic systems. These requirements, quite naturally, have stimulated ramjet and turbojet missile development programs. In order to meet these stringent performance requirements, fuels with high volumetric heating values must be used. The reason, therefore, for the evolution of Shelldyne®, Shelldyne-H®, and eventually the RJ-5 specification (Table 1) is not surprising since it has the highest density of any hydrocarbon which remains a fluid down to -65°F. The lower temperature limit of -65°F is currently required for all air launched missiles.

Shelldyne-H® type fuels are going to play a greater role in the future plans of both the Air Force and Navy. Efforts are currently underway to make RJ-5, or modifications thereof, more meaningful to the engine and systems designers.

Over the last ten years, approximately 10,000 gallons of Shelldyne® or Shelldyne-H® have been produced by Shell Oil Company affiliates, both in this country and in Europe. The process for producing this material has been

patented[4-14] and articles in the open literature have delved into the chemistry of the process[15-21]. Shelldyne-H® is a registered name of a hydrocarbon produced by hydrogenating the dimers of norbornadiene (HNBD). Until approximately five years ago, the fuel was not hydrogenated (Shelldyne®) and because of reactive double bonds was subject to instability during storage. The Shell Development Company has produced approximately 6700 gallons of Shelldyne-H® for AFAPL sponsored engine and fuel system development programs[22,23]. In September 1973, Shell Oil Company licensed Ashland Oil Company exclusive rights to produce Shelldyne-H®.

As pointed out initially, the great potential of Shelldyne-H® as a missile fuel is blighted by its high viscosity, particularly at sub-zero temperatures. This problem is one which can be alleviated either by system design or by fuel modification. Fuel system design incorporating either expulsion techniques or tank heating have been proposed as possible solutions to the flow problems at low temperatures[24,25]. More conventional fuel systems would probably rely more on the modified Shelldyne-H®. The potential of diluting Shelldyne-H® with lighter hydrocarbons is investigated in this effort and reported in this report. The effect of the various diluents on not only the viscosity but the density and heat of combustion of Shelldyne-H is considered and evaluated.

Another problem in using Shelldyne-H® at low temperatures, which became evident in the past year, is the tendency of some batches of fuel to freeze at temperatures above -65°F. This phenomenon is related to the conformation of the dimers which make up Shelldyne-H® and the fact that some batches of

material have higher freezing points than others. For the most part, the higher freezing points have not been detected in conventional laboratory tests because the material can be supercooled. The supercooling is a paradoxical phenomena which might be related to many things including the rate of cooling. In the case of a fast cooling rate, the viscosity of Shelldyne-H® is thought to increase so rapidly that the individual molecules are unable to rearrange themselves into the appropriate crystalline order before solidification. Crystallization might then occur after some time at this low temperature or might even occur upon being heated as the molecules become more mobile but are still below the actual freezing/melting point of the material. The possibility of any freezing occurring at temperatures above -65° must be understood and alleviated if Shelldyne-H® is to be used in air launched systems. Supercooling to below the actual melting point of Shelldyne-H® cannot be relied upon since the presence of such miscellaneous potential nucleation sites as dust, water crystals, sharp metallic surfaces, etc., cannot be completely eliminated from fuel systems. Therefore, the true melting point of Shelldyne-H® must be lowered to a temperature below the minimum system requirement which is normally -65°F for Air Force air launched systems.

Shelldyne-H® is composed of at least three major dimers which make up more than 98% of the material. The mixture of these hydrocarbons produces a eutectic which has a melting point considerably lower than the pure dimers. By using a preparative gas chromatographic technique, chemists at AFAPL were able to separate the three major dimers that make up Shelldyne-H®. In order to

justify future research into the chemical modification, it was of interest to see whether any combination of two or more of these dimers would not freeze above -65°F. Numbered according to their gas chromatographic elution time, the dimers of Shelldyne-H® were found to freeze at approximately 92°F, 41°F and 46°F, respectively. Normally, Shelldyne-H® will contain between 10-20% of dimer -1, 16-22% of dimer -2 and 55-75% of dimer -3. Since the last two dimers had the lower freezing points, a preliminary program was initiated to determine whether mixtures of only these two dimers could form eutectics which would meet the -65°F (and lower) melting/freezing point restriction.

The series of mixtures of only dimer -2 and -3 were made and tested (Monsanto Research Corporation contract AF33615-72-C-1071). Using weight percent concentrations from 0 to 100% in approximately 10% increments, these mixtures were stored for up to eight days in a controlled low temperature bath at -65°F. The results of this test are summarized in Table II. After eight days at -65°F, only mixtures containing 29.9, 40.3, 49.5 weight percent of dimer -2 were still liquids. Since not all batches of Shelldyne-H® which contain the three major dimers freeze above -65°F, research efforts are currently underway to ascertain which concentrations of the three dimers are required. When this is determined, production reaction conditions could be adjusted to produce the desired concentration of the dimers which have true melting points below -65°F. The Shelldyne-H® used in this program was composed of the three major dimers and had a melting point below -65°F.

The principal objective of this research program was to study the effect of various hydrocarbon fluids on reducing the low temperature viscosity of

Shelldyne-H®. It was also of interest to determine the effect of the diluent on the density and energy of the Shelldyne-H®. Previous[1,2] efforts had indicated that considerable reductions could be obtained in viscosity with only small losses in density and energy. Shell Development Company, under AF contract, studied the effects of different hydrocarbons (methylcyclohexane, decalin, dimethanodecalin, n-heptane and JP-7 fuel) in reducing the viscosity of Shelldyne-H® fuel at temperatures from -65°F to 73°F. Concentrations as small as 1 weight % diluent resulted in substantial reduction of the viscosity of Shelldyne-H® without any significant changes in other properties of the fuel. Of the diluents tested in the Shell program, methylcyclohexane had the greatest effect in reducing the viscosity of Shelldyne-H®.

TABLE II

EFFECT OF 8 DAY SOAK AT -65°F ON HNBD DIMER -2 AND -3 MIXTURES

SAMPLE NUMBER	DIMER -2, WT %	DIMER -3, WT %	RESULTANT PHASE*
1	0	100	S
2	9.9	90.1	S
3	20.9	79.1	S
4	29.9	70.1	L
5	40.3	59.7	L
6	49.5	50.5	L
7	60.0	40.0	S
8	70.1	29.9	S
9	81.9	18.1	S
10	89.8	10.2	S
11	100	0	S

* S - SOLID

L - PHASE

SECTION III
EQUIPMENT

The experimental portion of this program was carried out on the Model R17 Weissenberg Rheogoniometer which was modified to measure liquid viscosities at temperatures down to -100°F or below. This device is a refinement of a design by Weissenberg and is manufactured by Sangamo Controls, Ltd., Bognor Regis, England, and is distributed in this country by the Technidyne Corporation, Louisville, Kentucky.

The rheogoniometer was developed as a research instrument to measure stress vs. rate of shear dependence at every point in the fluid under test in both the tangential and normal planes. For this program, only the ordinary tangential data were obtained since the liquids were simple Newtonian fluids. Figure 2 is a photograph of the rheogoniometer and associated equipment. The main components are from left to right, the drive unit (including motor, gearbox and drive shaft), the main body, instrument controls, and recording equipment. The measuring section of the rheogoniometer is very precisely engineered and is shown within the main body in Figure 3. Not shown in these figures are the modifications needed to get test conditions down to -65°F. This was accomplished by using cold nitrogen to cool the platens which were enclosed in the temperature control chamber which is shown in an opened position in Figure 3. The nitrogen actually served a dual purpose of cooling the platens and providing a dry, inert atmosphere around them. The gas passed into the test chamber through special gas inlets. This gas was cooled by heat exchange in a 25 foot coil of 5/16 inch OD copper tubing submerged in a dewar of liquid nitrogen. Temperature control within the

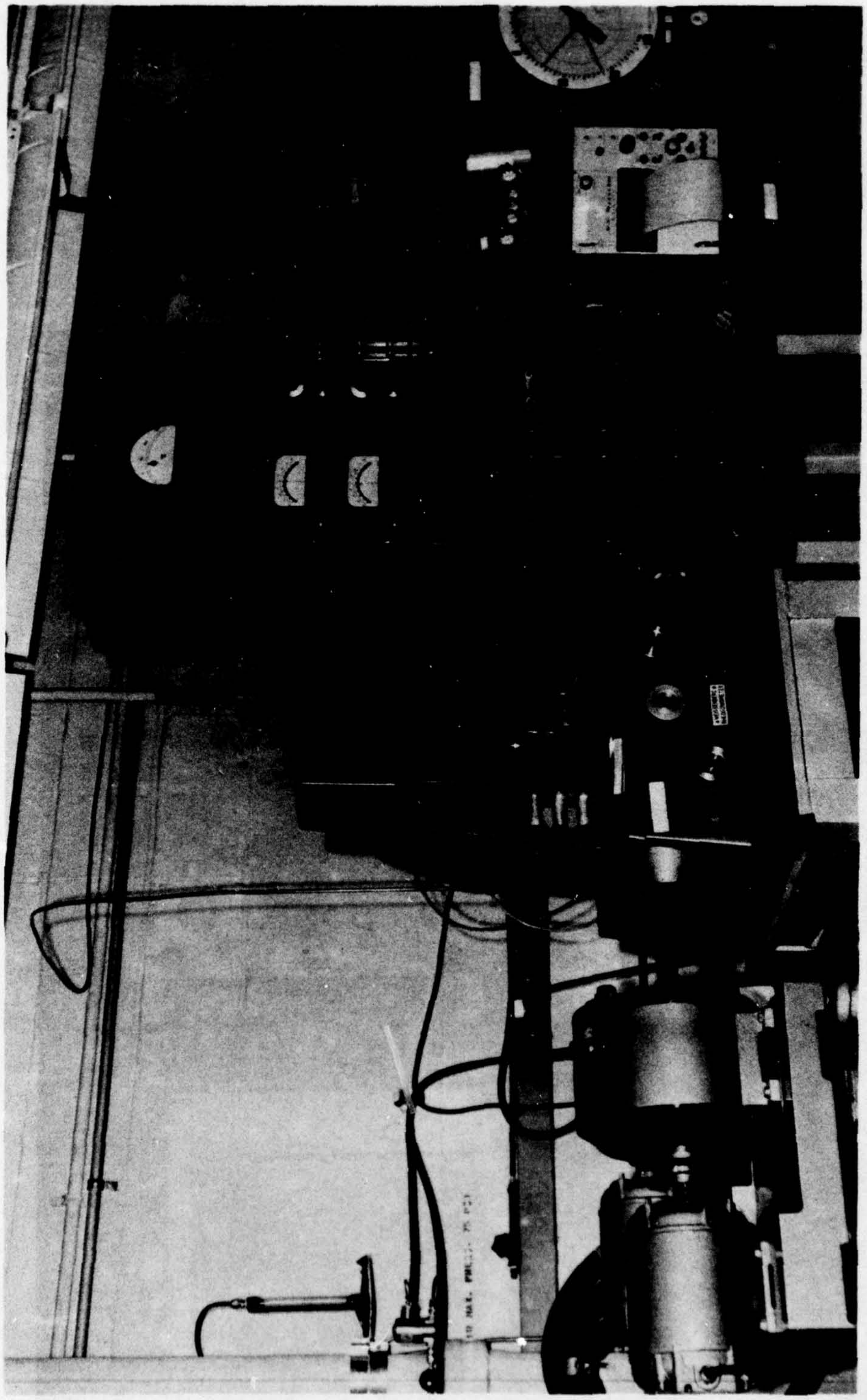


Figure 2. Photograph of AFAPL Weissenberg Rheogoniometer and Ancillary Equipment

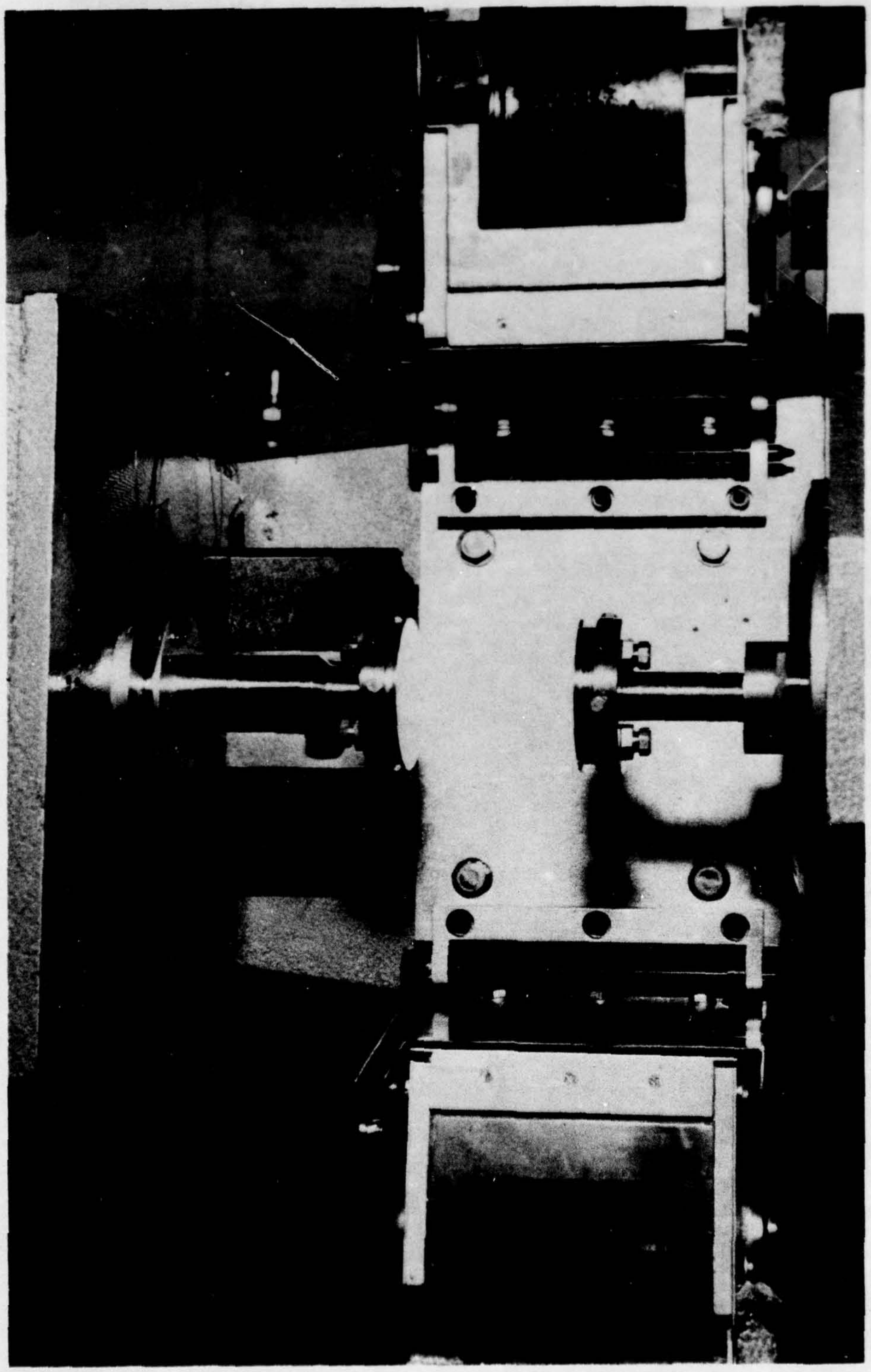


Figure 3. Photograph of the Measuring Section of the Weissenberg Rheogoniometer

chamber was achieved by adjusting the flow rate of cold nitrogen. The temperature of the test platens was detected by a copper-constantan thermocouple embedded in the outer surface of the top platen. The temperature was indicated on a Digital Voltmeter, Series X-3, manufactured by Non Linear Systems, Inc., Del Mar, California.

The basis of the rheogoniometer is the single cone and plate viscometer which is pictured in the center of Figure 3. This device has evolved into a very useful instrument for both industrial and research organizations. It has the versatility and sensitivity to measure the viscosity of fluids from 10^8 poise down to the thinnest of materials. It has been reported[26] that the viscosity of air has been measured with 100 times more sensitivity because of the electronic equipment and associated ultra violet recorder. Thus, viscosities as low as 1×10^{-6} to 1×10^{-5} poise can be measured; therefore, the instrument has a range of approximately 10^{14}. The range of shear rates available in this instrument is from 10^{-3} to 10^4 sec^{-1}, although it is, of course, not possible to use high shear rates with thicker materials or to obtain measurable readings with low shear rates and thin materials.

The measuring section of the rheogoniometer is very precisely engineered (Figure 3). The operation of the instrument is relatively simple with a two-way drive box translating the continuous rotational drive from the gear box from the horizontal axis to a vertical axis through a gear reduction connected to a worm and wheel. Through this worm and wheel, the vertical shaft drives the lower cone. The viscous drag is transmitted through the sample to the upper platen which is attached to the rotor of an air-bearing

torsion head. This allows a small, but virtually frictionless circular movement of the upper platen against a calibrated torsion bar, and this movement is detected by a linear displacement inductive transducer capable of measuring down to 0.1 micron of platen movement.

The fluid to be tested is sheared between the rotating cone and the fixed flat platen. The basic shear-rate shear-stress relation of the fluid is obtained from the measurement of the rotational speed and the torque required to drive the platen. Since the angle between the cone and plate is small, the shear stress will be very nearly uniform throughout the fluid. Frederickson[27] reported that the percentage difference in shear stress between cone and plate for cone angle less than 4° was less than 0.5%; for the AFAPL 2° cone angle, the difference in shear stress was only 0.12%. Therefore, the assumption that shear stress and, hence, shear rate and apparent viscosity are uniform throughout the fluid, is an excellent one. For the Newtonian fluids studied in this program, the apparent viscosity is the same as the absolute viscosity.

The flow equations for the cone and plate viscometer have been developed (26,28) and the results of these developments are described in Appendix A.

In the research program, the Weissenberg Rheogoniometer, which had been procured originally for metal slurried fuel evaluation, was set up and adjusted according to the instruction manual[26].

Procedures for calibrating the electronics, calibrating the displacement transducers, changing the torsion bars and changing and aligning the plates were followed as outlined in the manual.

The testing performed on this program was carried out on one set of platens, using only one torsion bar. Pertinent data on these test specimens are outlined in Table III.

Calibration tests were performed on Brookfield Engineering Laboratory, Inc. Viscosity Standard Fluids. The purpose of these tests was to determine the accuracy of the instrument on fluids of known viscosity. The results of these initial tests are outlined in Table IV. The standard fluids cover the viscosity range of interest and all tests were performed at room temperature.

With the exception of the "11900.0 centipoise" standard, the data obtained on the AFAPL rheogoniometer was generally within 5% of the Brookfield reported values. Since most of the data obtained in this program would be below 5000 centipoise, the test set-up seemed adequate from an accuracy standpoint.

Another area of concern in running the cone and plate rheogoniometer is the effect of "gap setting" on test results. Based on the theory of plate and cone viscosity, it is vital for the sake of accuracy that the point of the cone just touch the center of the flat plate. This, of course, would disturb the torque reading; therefore, the point of the cone is truncated to prevent interference. This gives negligible error since the torque produced at the center of the plate is immeasurable; however, it is vitally important to adjust the gap as accurately as possible so that the imaginary tip of the cone would just touch the center of the plate. The amount of truncation in microns is determined by the manufacturer and is etched in the back of each cone; this measurement is used in setting the gap. The procedure used in "gap setting" is outlined in the instruction manual[26]. Since most of our testing would be

TABLE III

CHARACTERISTICS OF TEST PLATENS AND TORSION BAR

Item	Description
Cone Platen	Number 1140, diameter 5 cm, actual cone angle 2° 0' 22" - Apex of cone - 91 microns
Flat Platen	Number 865, diameter 5 cm
Torsion Bar	Number 6/26 Constant, $K_T = 1.851 \times 10^1$ $\frac{\text{dyne-cm}}{\text{microns}}$

TABLE IV

RHEOGONIOMETER RESULTS ON BROOKFIELD VISCOSITY STANDARDS

Test Temperature: 78°F
Cone Platen Nr : 1141
Flat Platen Nr : 865
Torsion Bar Nr : 6/26

Brookfield Standard Fluid Viscosity Centipoise @ 77°F	AFAPL Test Viscosity Centipoise @ 78°F	% Error
5.1	5.1	0
9.0	9.05	+0.5
49.0	49.85	+1.7
96.0	99.70	+3.9
470.0	482.78	+2.7
1010.0	1012.79	+0.3
4750.0	4880.28	+2.7
11900.0	12954.25	+8.9
31200.0	32535.16	+4.3

carried out at various temperatures from ambient to -65°F, it was necessary to determine the effect of thermal expansion on "gap setting" and, in turn, the effect of "gap setting" error on test results. It was reported[26] that the gap between the truncated cone and flat plate would close at about 0.69 microns per °F when the plates were heated. This figure is only approximate depending mainly on the rate and pattern of cooling of the instrument, particularly, air bearing rotor and lower extension piece immediately above and below the temperature control chamber. Since our program was primarily concerned with low temperature viscosity, care had to be exercised so that the gap was accurately set at each test temperature.

A series of tests was performed on the rheogoniometer using the test platens and torsion bar where the gap was set at 91 microns at 75°F and the test chamber temperature was, stepwise, reduced to -65°F. The change in "gap setting" was then determined using the special gap setting knob which is unique to the Model R17 Rheogoniometer. It was found that the "gap setting" increased by 0.82 microns per °F as the temperature was lowered from 75°F to -65°F; this agrees closely with the 0.69 microns per °F reported by the manufacturer.

In order to ascertain the effect of any "gap setting" error on test accuracy, a series of tests was performed on the 470 centipoise "Brookfield Standard" silicone fluid. These tests were performed at 78°F and outlined in Table V. These data substantiate the fact that errors in "gap setting" could appreciably alter the accuracy of viscosity measurements on the cone and plate rheogoniometer. With the platens and torsion bar used in this program,

it is safe to assume that if the gap setting is within ± 20% of the designated value, an accuracy of 5% is possible.

TABLE V

EFFECT OF GAP SETTING ERROR ON ACCURACY

Test Platens: 5 cm (2° cone angle)
Torsion Bar: 2/26
Test Fluid: 470 centipoise silicone fluid
Test Temperature: 78°F

Gap Setting, Microns	Viscosity, Centipoise	% Error in Gap Setting	% Error in Measured Viscosity
91	482.78	0	0
75	503.77	-17.58	+4.35
50	535.26	-45.05	+10.87
91	482.78	0	0
116	459.17	27.47	-4.89
141	419.80	54.95	-15.00

For viscosity measurements in this program, care was exercised in setting and adjusting the gap for each test temperature. This was done by obtaining data on the effect of temperature on "gap setting"; these data were then used to develop a plot of "gap setting" adjustment versus temperature. This plot and the operative procedure used at various temperatures are outlined in Appendix B.

Considerable confusion exists concerning the units used to express viscosity. In this program, the metric system was used. In this system, the unit of absolute viscosity is the poise which is equal to 100 centipoise. The poise has the dimensions of dyne seconds per square centimeter, or of grams per centimeter/second. In order to circumvent any confusion concerning vicosity units, the centipoise is used exclusively in this report. As a point of reference, the kinematic viscosity is the ratio of the absolute viscosity to the mass density. In the metric system, the unit of kinematic viscosity is stoke. The stoke has dimensions of square centimeters per second and is equal to 100 centistokes. The kinematic viscosity in centistokes of any material at a given temperature is equal to the absolute viscosity in centipoise of the material at the given temperature divided by the mass density (grams per cubic cm) of the material; again, at the given temperature.

In addition to the viscosity data, the densities and heating values of each of the blends were calculated. The goal of the program was to evaluate the effects of dilution on the viscosity and density of Shelldyne-H® fuel in order to formulate more suitable fuels from the fuel system design aspect.

SECTION IV
PROGRAM

With proper dimer ratio, pure Shelldyne-H® will remain a homogeneous fluid down to temperatures below -65°F. The batch of Shelldyne-H® used in this program was Shell Development Company's Batch Nr LR-11410-103 which did not freeze above -65°F. Figure 1 is a plot of the viscosity of this fluid as a function of temperature. Figure 4 is a chromatogram of this batch of material; the composition of the fluid is discussed in Reference 29, where it was reported that there were 10.3%, 16.8% and 72.0% of the three major dimers and 0.9% of a fourth component that eluded from the column between the second and third major components. The chemical and physical analyses of this batch, as reported by Shell Development, are outlined in Table VI.

The objective of this program was to investigate the effect of various hydrocarbons on reducing the high viscosity of Shelldyne-H®. Since Shelldyne-H® is of interest as a fuel, it was also of interest to determine the effect of hydrocarbon diluents on the heat of combustion. The hydrocarbons, used as diluents in this program, are presented in Table VII, together with the supplier and the grade. These materials were blended in concentrations of approximately 5, 10, 25, 35 and 50 weight percent in Shelldyne-H® and the viscosities of the resulting blends were measured at selected temperatures between -65°F and 70°F. As mentioned previously, all testing was conducted using the 5 cm platens with 2° 0' 22" cone angle; the smallest torsion bar (Nr 6/26) available was also used in all the testing reported herein.

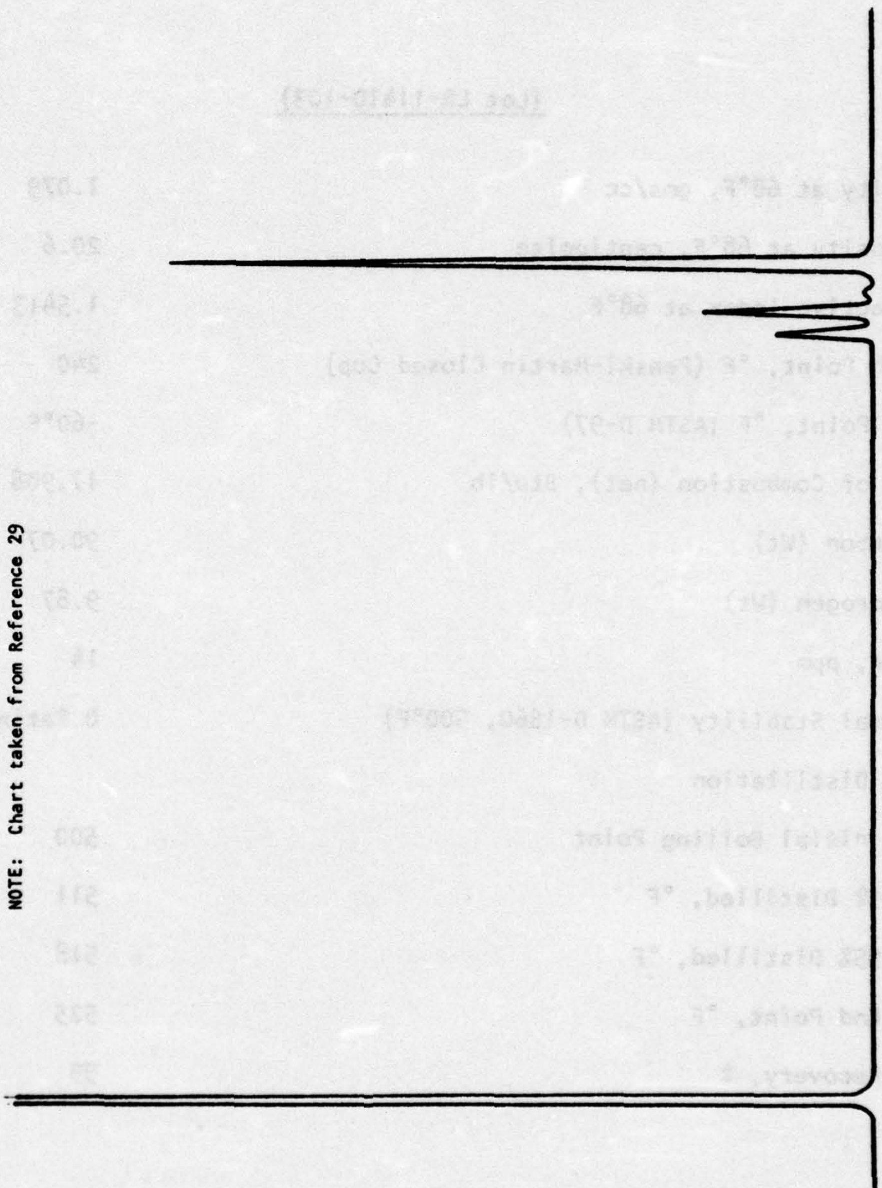


FIGURE 4. Chromatogram of Shelldyne-H®, Lot Nr LR-11410-103

NOTE: Chart taken from Reference 29

TABLE VI

SHELLDYNE-H® ANALYSIS

(Lot LR-11410-103)

Density at 68°F, gms/cc	1.079
Viscosity at 68°F, centipoise	20.6
Refractive Index at 68°F	1.5413
Flash Point, °F (Penski-Martin Closed Cup)	240
Pour Point, °F (ASTM D-97)	-60°F
Heat of Combustion (net), Btu/lb	17,908
% Carbon (Wt)	90.07
% Hydrogen (Wt)	9.87
Water, ppm	14
Thermal Stability (ASTM D-1660, 500°F)	0 Rating
ASTM Distillation	
Initial Boiling Point	500
5% Distilled, °F	511
95% Distilled, °F	518
End Point, °F	525
Recovery, %	99

TABLE VII

PROGRAM TEST FLUIDS

FLUID	GRADE	SUPPLIER
Methylcyclohexane	High Purity	Shell Development Co.
Decahydronapththalene (decalin)	High Purity	Shell Development Co.
Tetrahydronaphthalene (tetralin)	Purified	Fisher Scientific Co.
Toluene	Reagent	J. T. Baker Chemical
Cis-decalin	99%	Chemical Samples Co.
Trans-decalin	99%	Chemical Samples Co.
Isobutylbenzene	99%	Chemical Samples Co.
Tetrahydro-methylcyclopentadiene dimer (TH-MCPD)	High Purity	Ashland Oil Company
Tetrahydro-norbornadiene	High Purity	Shell Development Co.

SECTION V
PROGRAM RESULTS

There is no reliable method for estimating the viscosity of liquid mixtures(31); therefore, all concentrations of interest had to be measured experimentally on the rheogoniometer. The viscosity data sheets obtained on the mixtures are included in Appendix D. These data were reduced into conventional viscometric terms and these have been tabulated in Appendix E. Appendix A outlines the mathematical procedure necessary to reduce the rheogonometric measurements into viscosities.

Figures 5-11 present the viscosities of the various blends as affected by temperature. For aid in determining the viscosity reduction produced by each diluent, the viscosity of "pure" Shelldyne-H® is also plotted on each figure. The diluents significantly reduced the viscosity of Shelldyne-H®, particularly at the lowest temperatures, even at low concentrations. As an example, the blend containing 5 weight percent toluene (Figure 5) reduced the -65°F viscosity of Shelldyne-H® by a factor of about 7 (from 31,457 centipoise to 4,489.9 centipoise).

Although the viscosity of Shelldyne-H® is reduced by the diluents over the entire range of test temperatures, the most significant effects are at the lower temperatures. The viscosity of Shelldyne-H® increases an order of magnitude between the temperatures of -40°F and -65°F; all the blends tested had less significant rises for this temperature range. It should be apparent to the missile designer that any arbitrarily selected temperature limit could seriously affect his choice of fuel.

FIGURE 5. The Effect of Temperature on the Viscosity of Various Shelldyne-H®/Toluene Blends

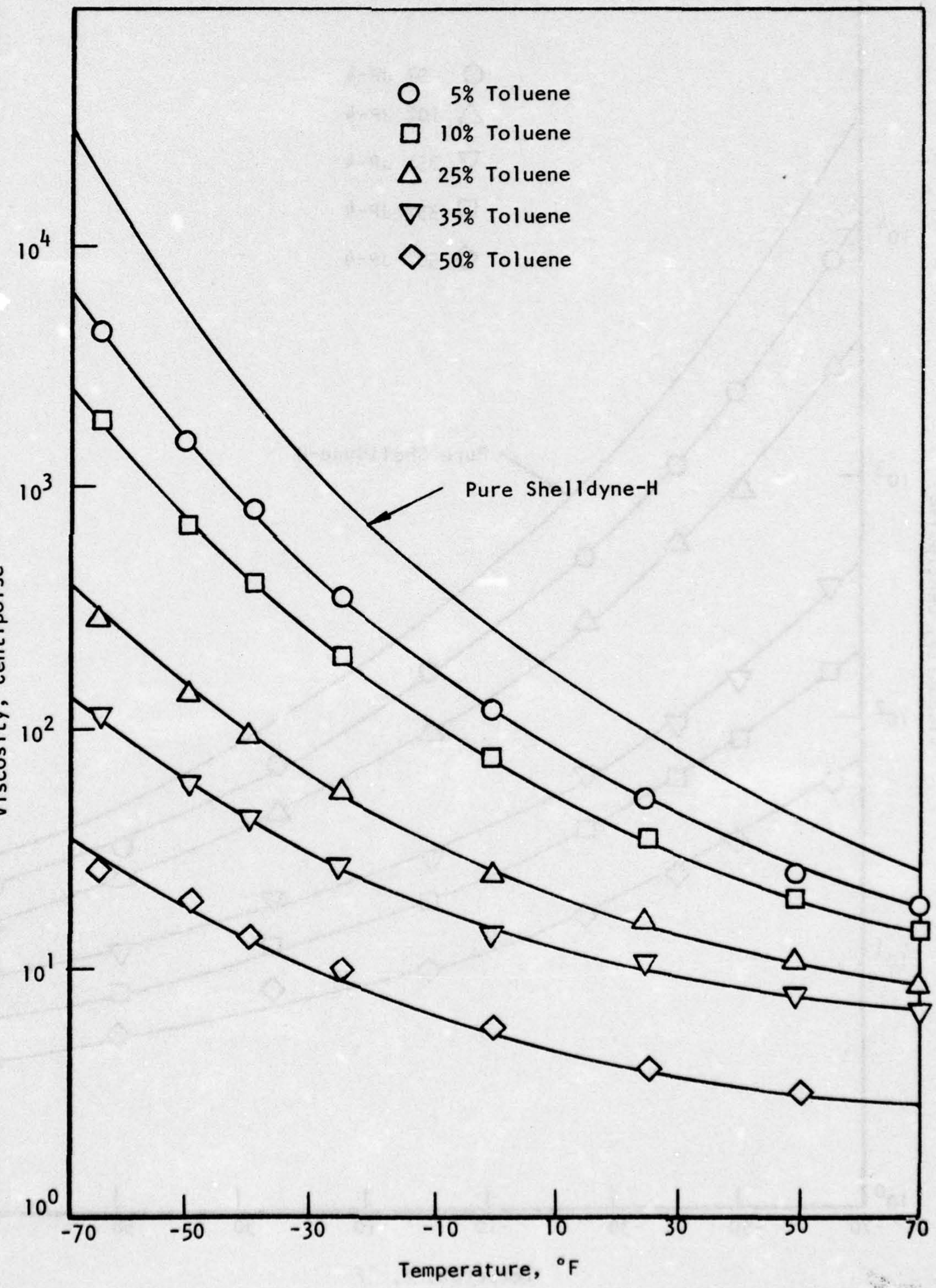


FIGURE 6. The Effect of Temperature on the Viscosity of Various Shelldyne-H/JP-4 Blends.

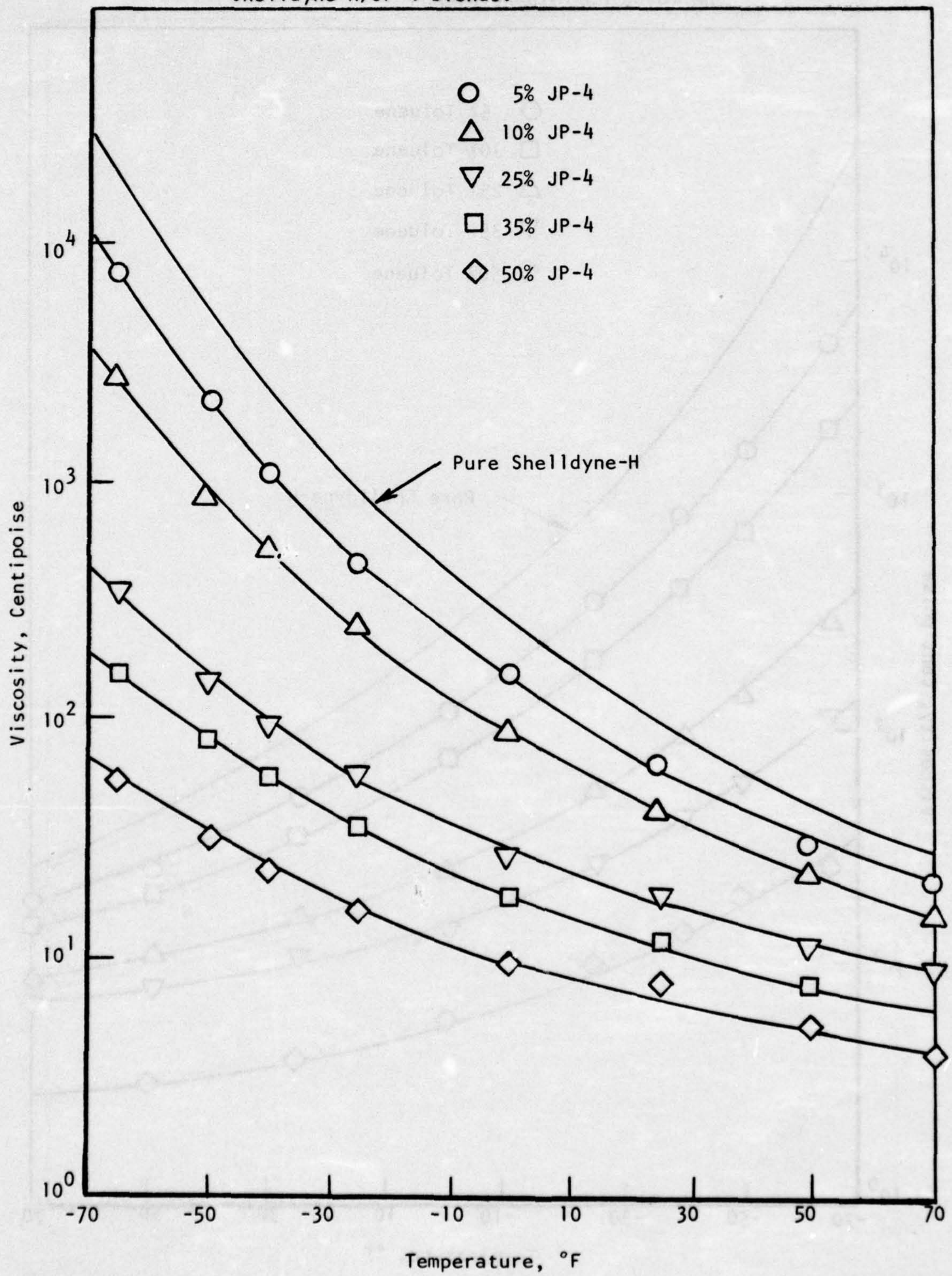


FIGURE 7. The Effect of Temperature on the Viscosity of Various Shelldyne-H/Methylcyclohexane Blends.

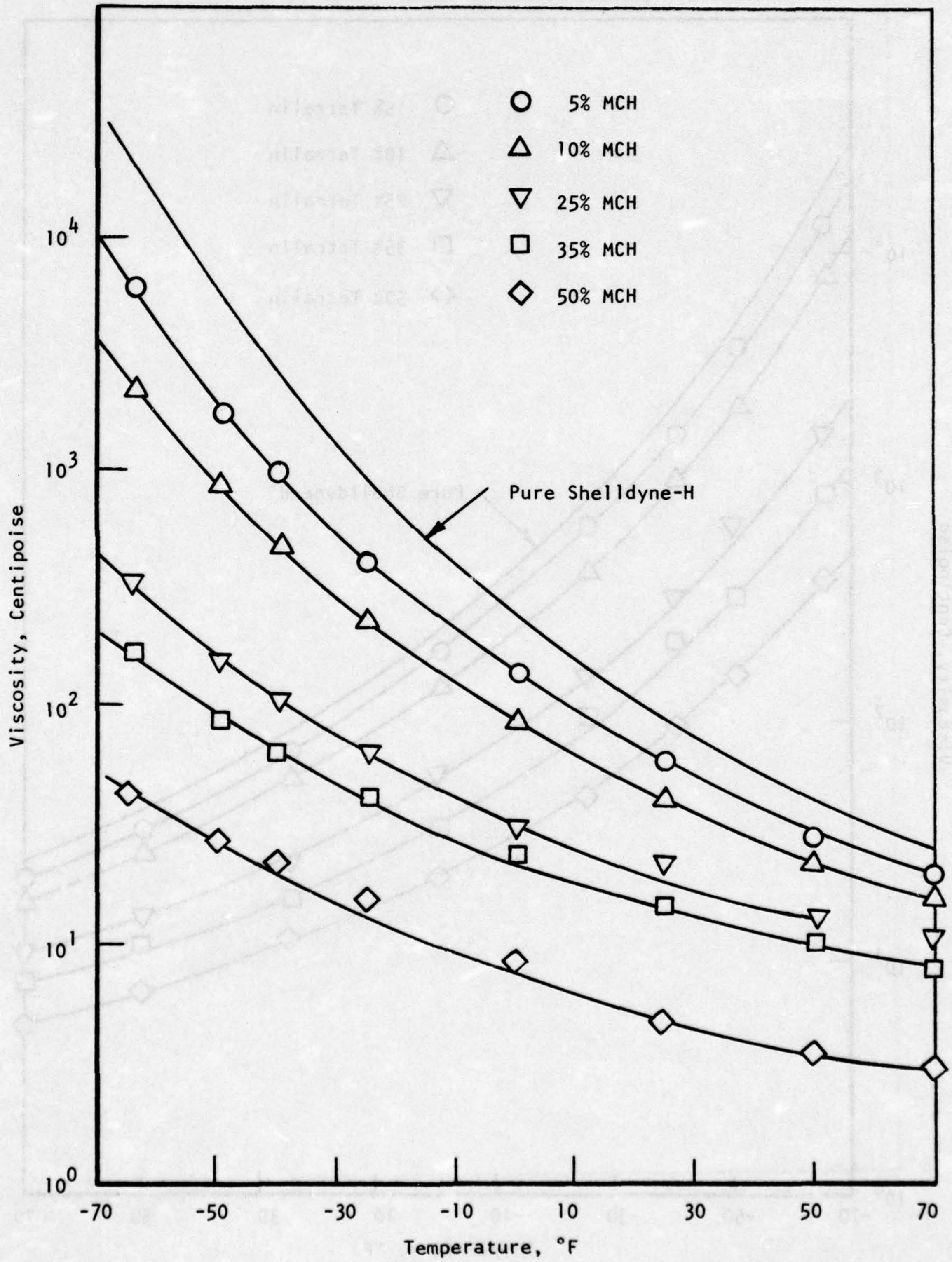


FIGURE 8. The Effect of Temperature on the Viscosity of Various Shelldyne-H/Tetralin Blends.

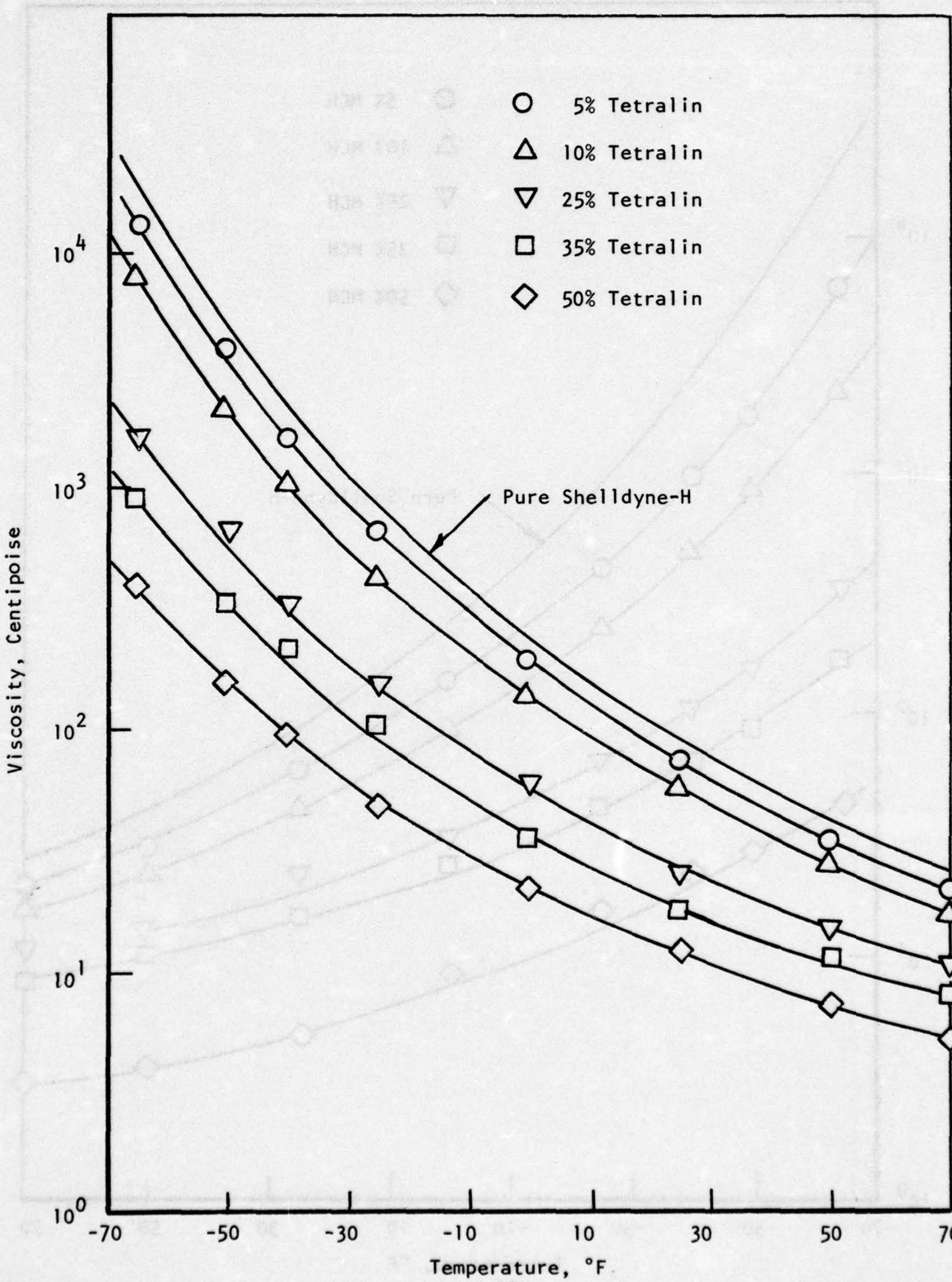


FIGURE 9. The Effect of Temperature on the Viscosity of Various Shelldyne-H/trans-Decalin Blends

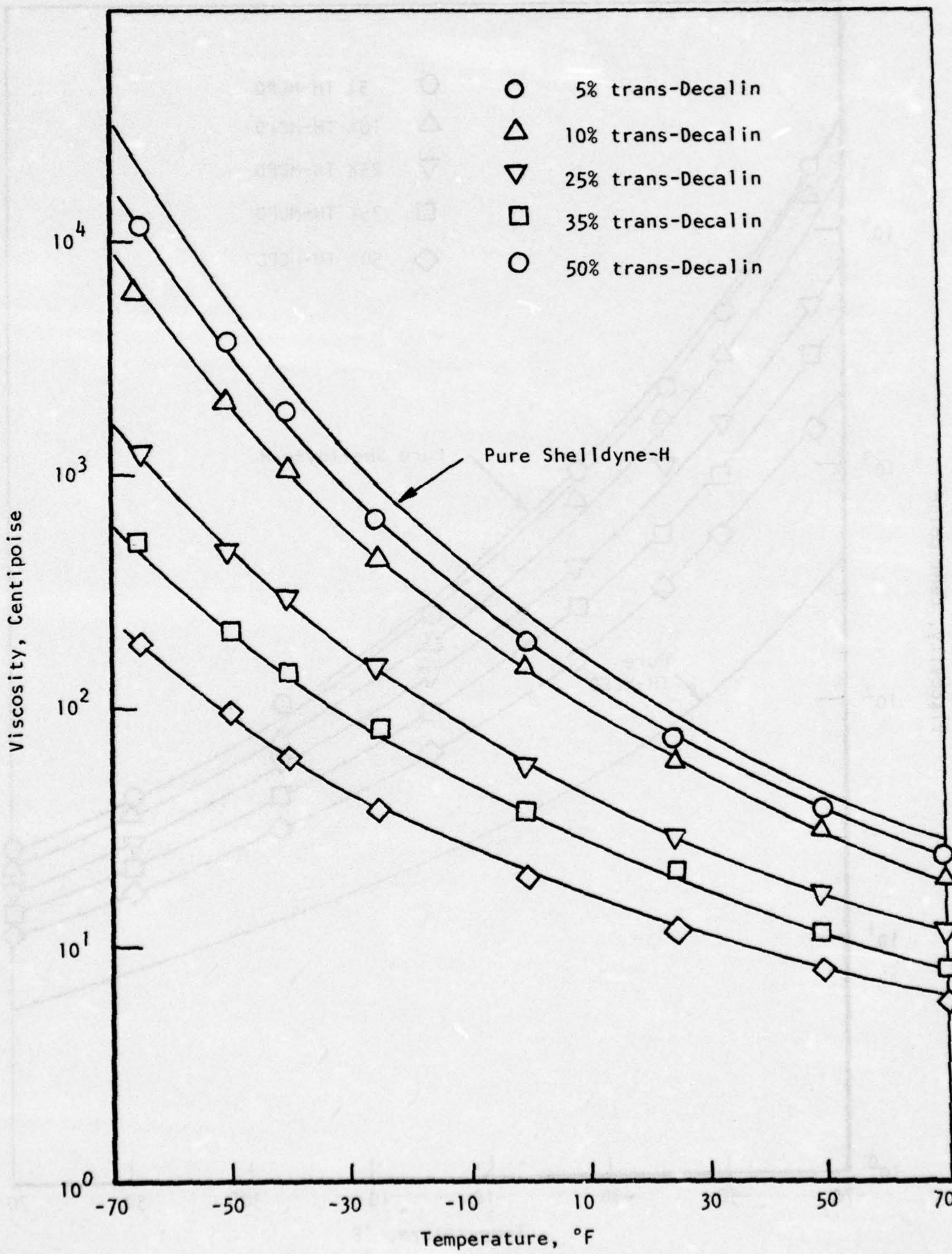


FIGURE 10. The Effect of Temperature on the Viscosity of Various Shelldyne-H/TH-MCPD Dimer Blends.

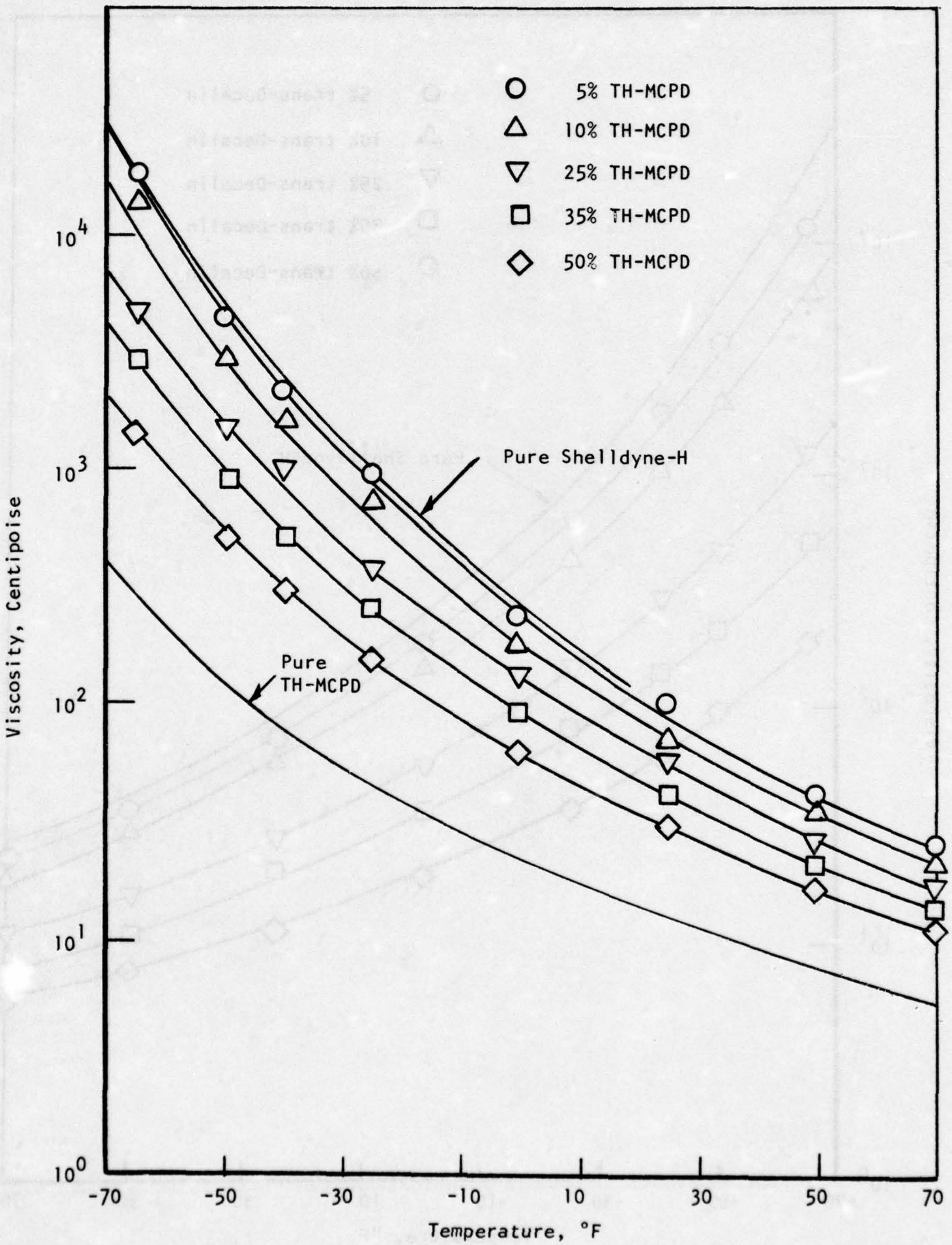
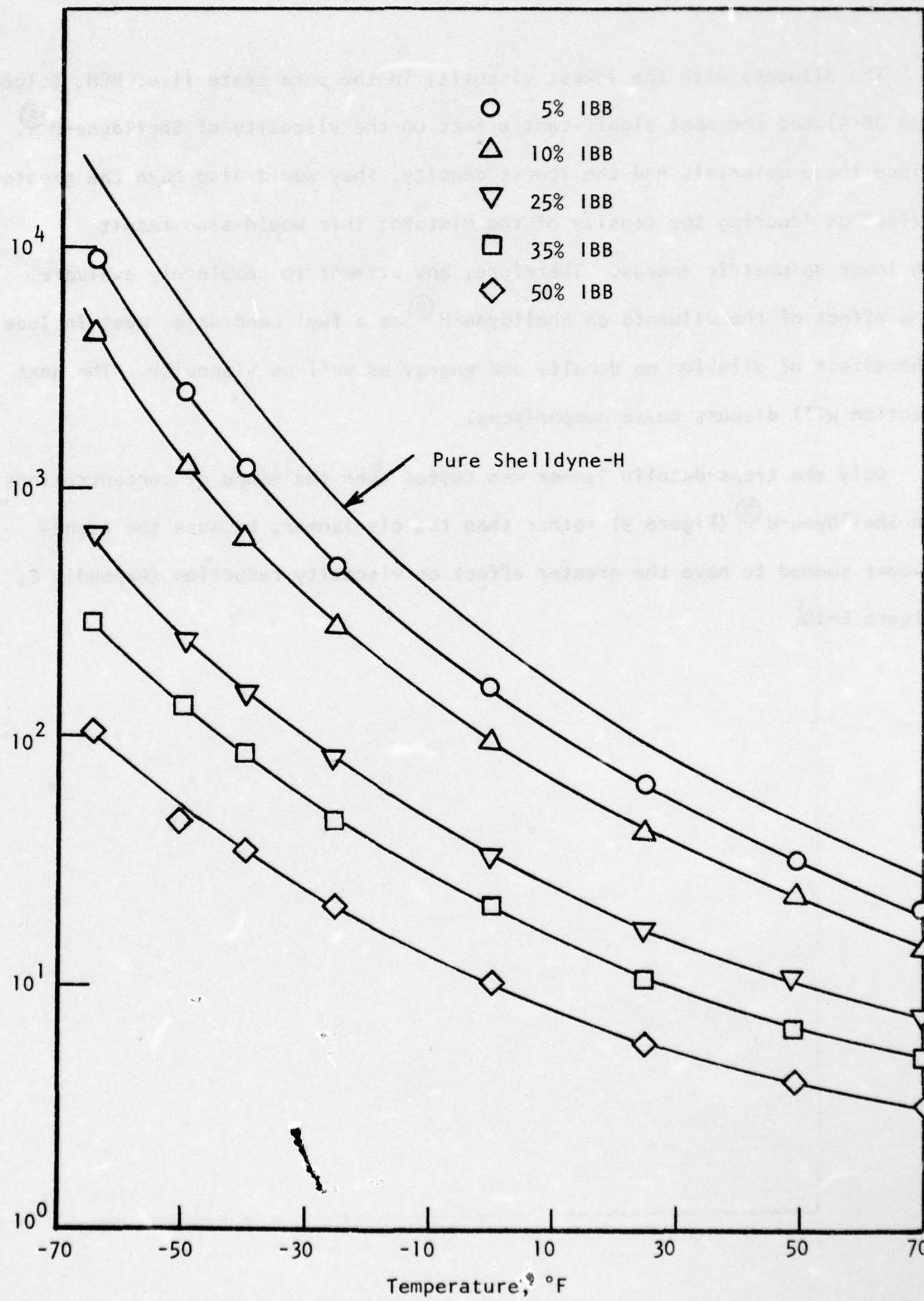


FIGURE 11. The Effect of Temperature on the Viscosity of Various Shelldyne-H/Iso-butylbenzene (IBB) Blends.



The diluents with the lowest viscosity in the pure state (i.e., MCH, toluene, and JP-4) had the most significant effect on the viscosity of Shelldyne-H®. Since these materials had the lowest density, they would also have the greatest effect on lowering the density of the mixture; this would also result in lower volumetric energy. Therefore, any attempt to completely evaluate the effect of the diluents on Shelldyne-H® as a fuel candidate, must include the effect of dilution on density and energy as well as viscosity. The next section will discuss these comparisons.

Only the trans-decalin isomer was tested over the range of concentrations in Shelldyne-H® (Figure 9) rather than the cis-isomer, because the trans-isomer seemed to have the greater effect on viscosity reduction (Appendix E, Figure E-10).

SECTION VI

DISCUSSION

In order to evaluate the effect of the diluents on the potential of Shelldyne-H ^{R} as a missile fuel, the analysis must include more than low temperature viscosity measurements. The attractiveness of Shelldyne-H ^{R} as a fuel is its density which results in a high volumetric heating value. Therefore, the heating value or net heat of combustion for each blend was estimated for each binary mixture and these data were plotted in Figures 12 through 18. The heat of combustion data were determined as outlined in Appendix F. The viscosity data in Figures 12 through 18 are those determined in this program.

The thinner hydrocarbons, such as methylcyclohexane and JP-4 are very effective diluents but they have low densities and low volumetric heating values which reduce these values when mixed with Shelldyne-H ^{R}. On the other hand, the heavier materials, such as TH-MCPD dimer, decalin and tetralin, do not have as great an effect on reducing the heating value of Shelldyne-H ^{R}, but larger quantities of these hydrcarbons are required to lower the viscosity of Shelldyne-H ^{R}.

In order to evaluate the effect of the various diluents, the -65°F data for each blend from Figures 12 through 18 are combined in Figure 19. The most effective blends tested, with regard to lowering viscosity at 65°F while retaining the highest volumetric energy, were those where toluene was the diluent.

Figure 20 is a plot similar to Figure 19, but only for -40°F viscosity data on the test blends. The relationship between the various test blends

FIGURE 12. Viscosity at Various Temperatures vs. Volumetric Heat of Combustion for Shelldyne-H/Toluene Blends

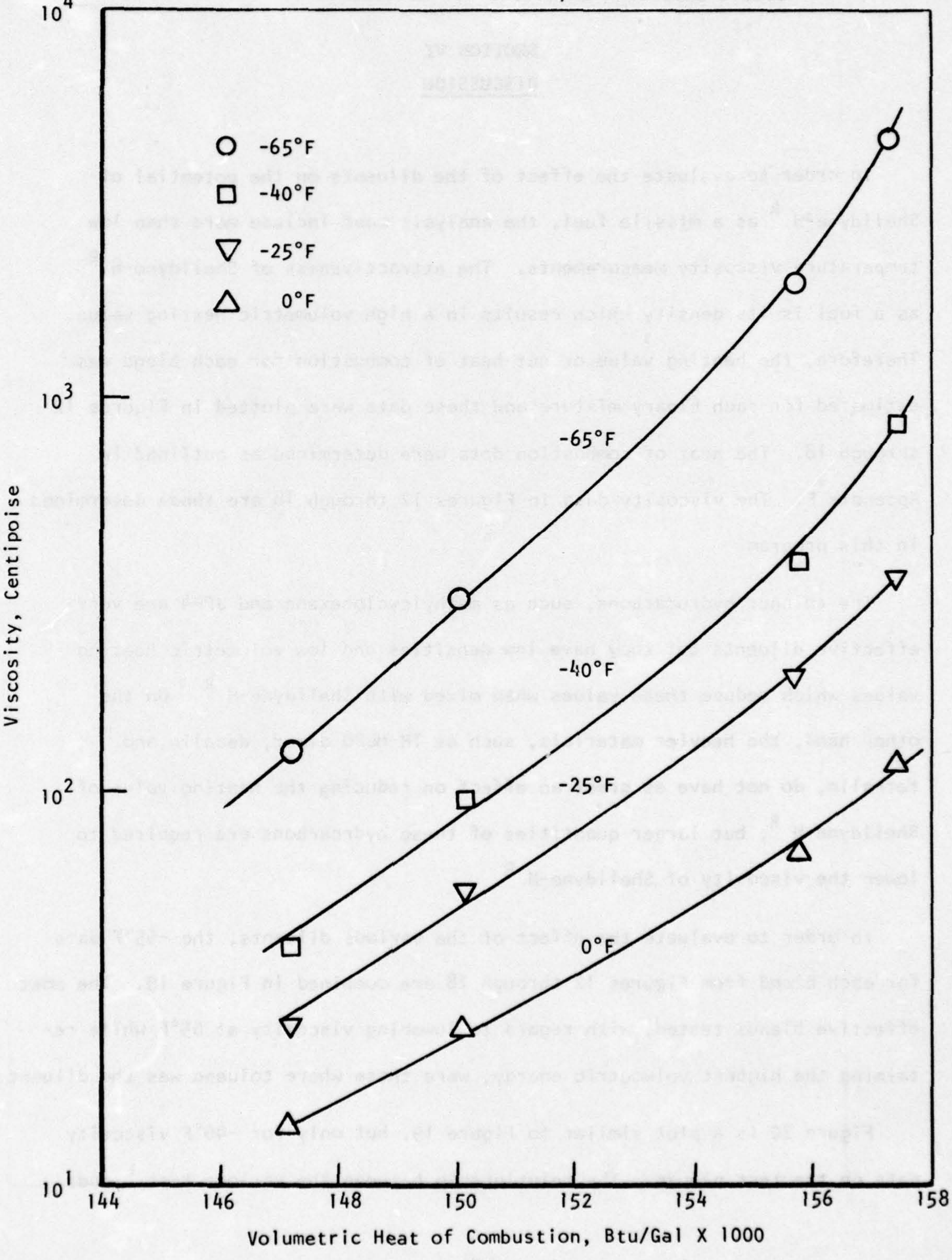


FIGURE 13. Viscosity at Various Temperatures vs. Volumetric Heat of Combustion for Shelldyne-H/JP-4 Blends

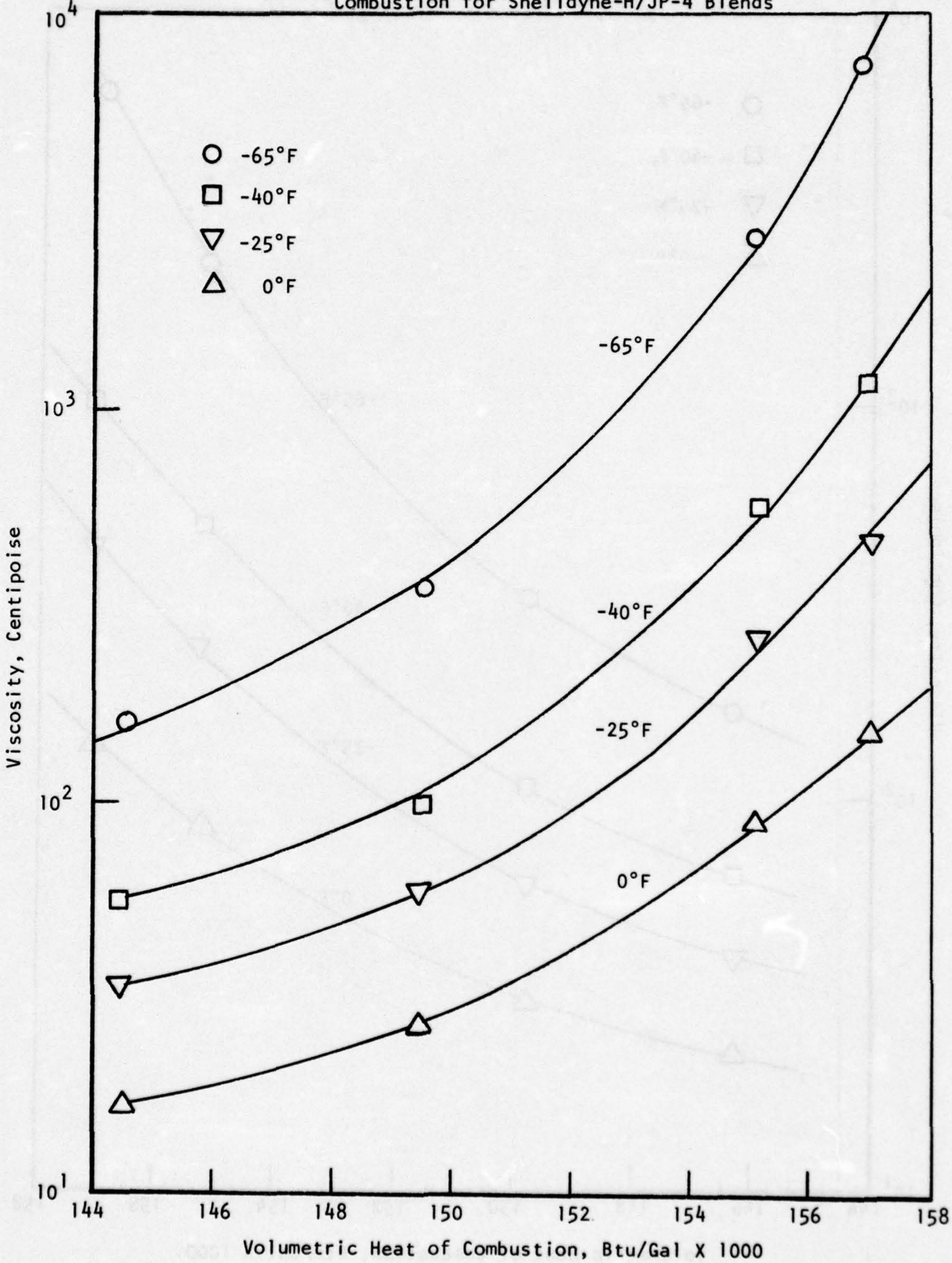
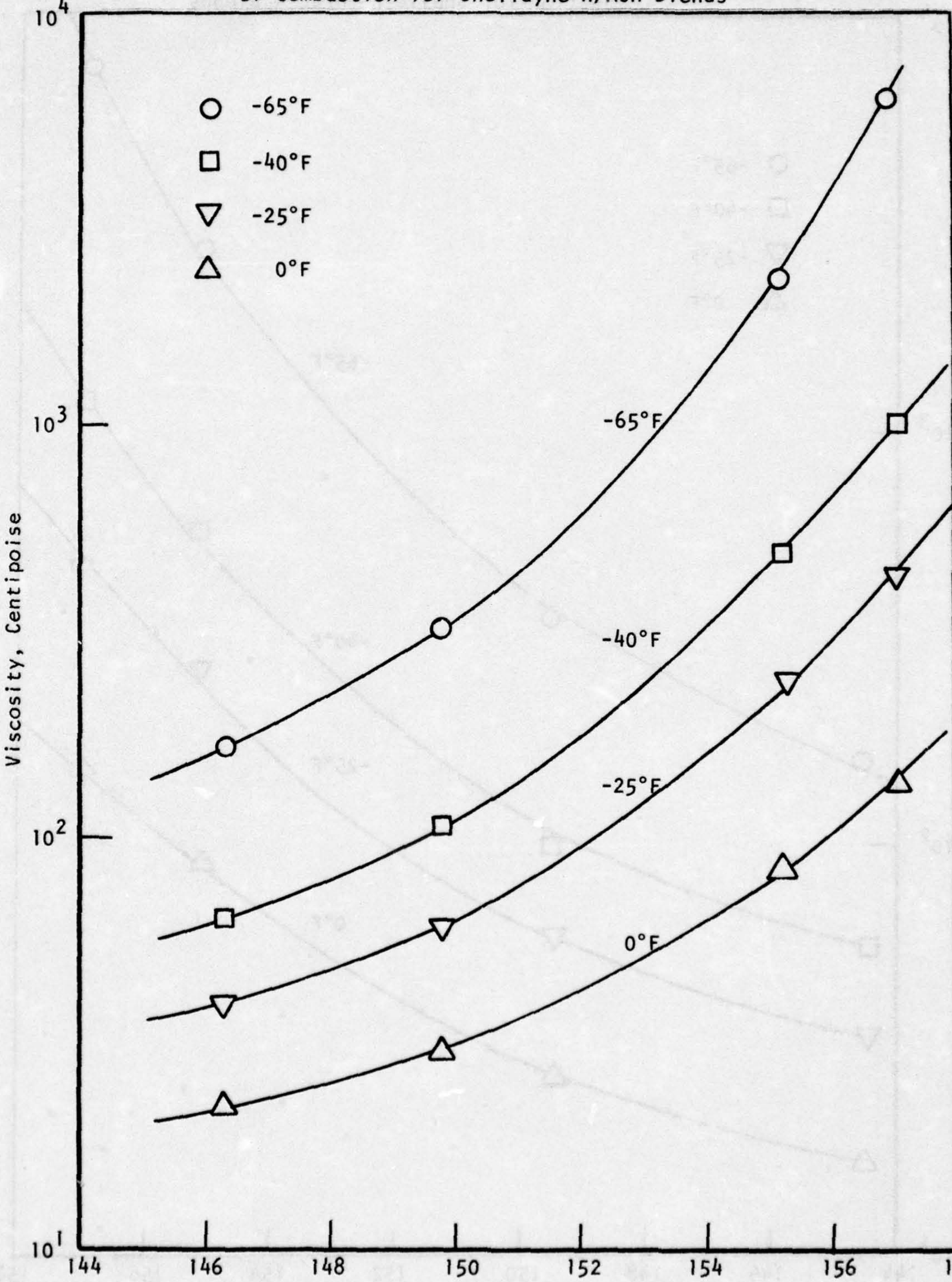


FIGURE 14. Viscosity at Various Temperatures vs. Volumetric Heat of Combustion for Shelldyne-H/MCH Blends



Volumetric Heat of Combustion, Btu/Gal X 1000

FIGURE 15. Viscosity at Various Temperatures vs. Volumetric Heat of Combustion for Shelldyne-H/Tetralin

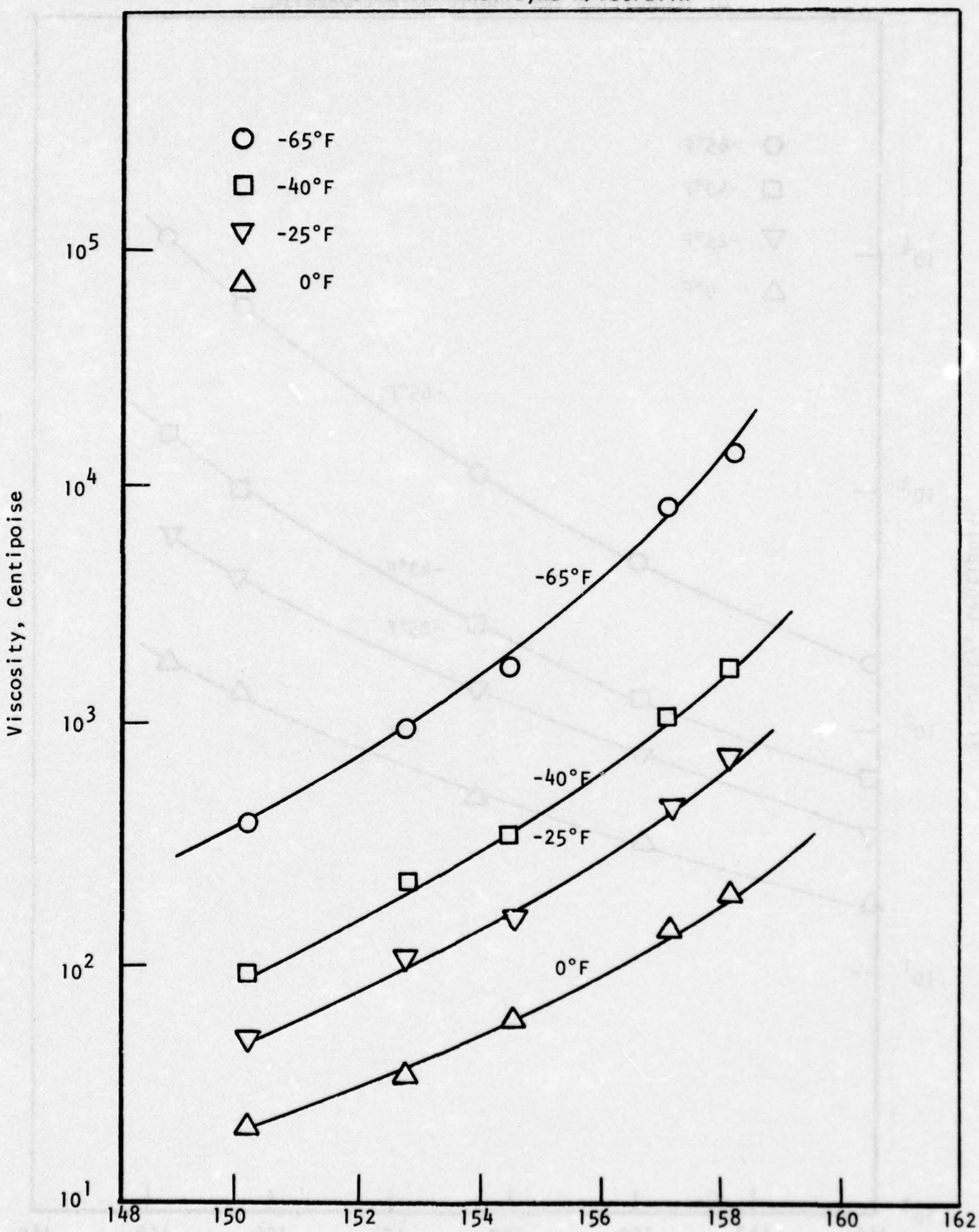


FIGURE 16. Viscosity at Various Temperatures vs. Volumetric Heat of Combustion for Shelldyne-H/t-Decalin

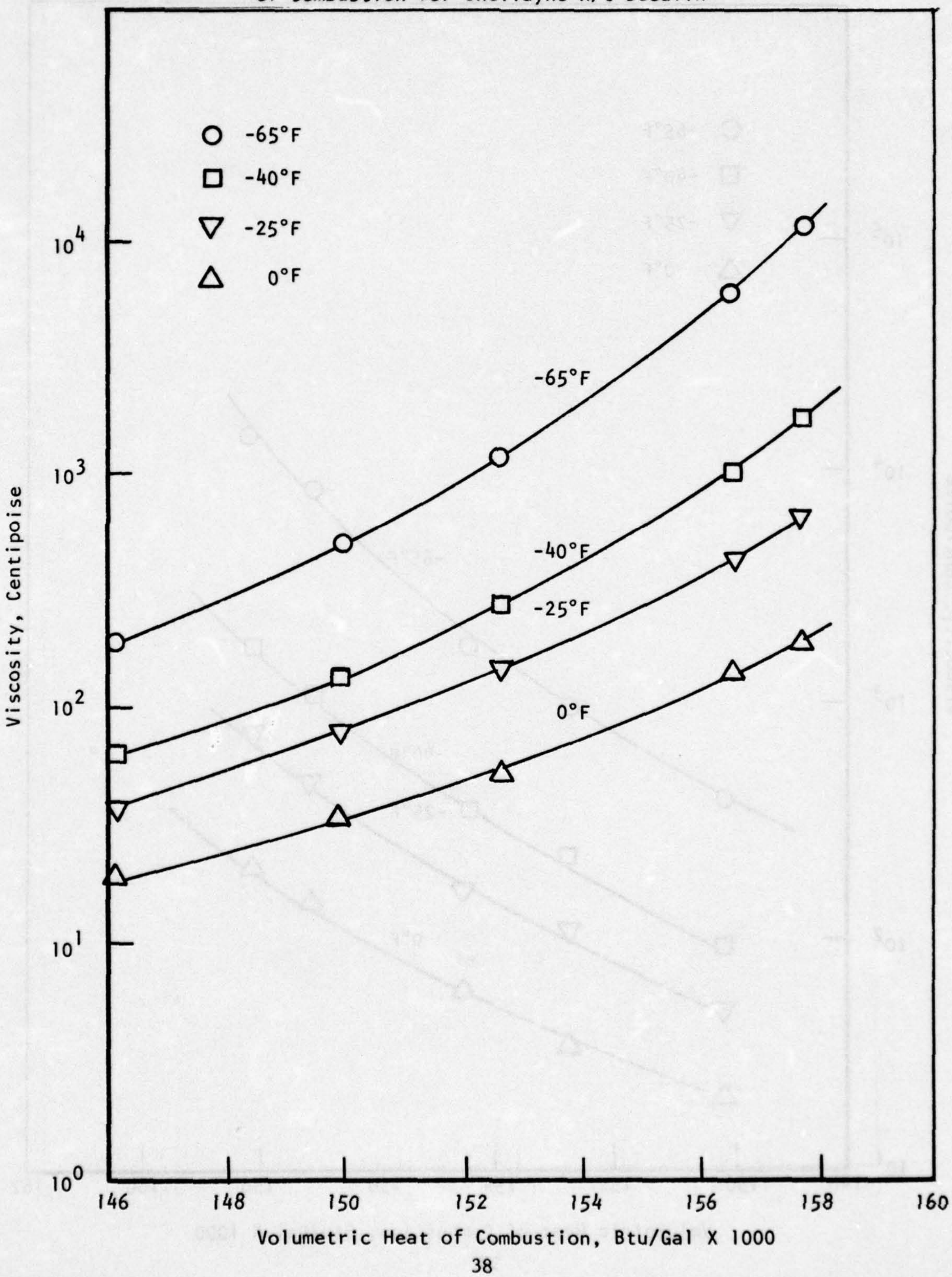


FIGURE 17. Viscosity at Various Temperatures vs. Volumetric Heat of Combustion for Shelldyne-H/Th-MCPD Dimer Blends

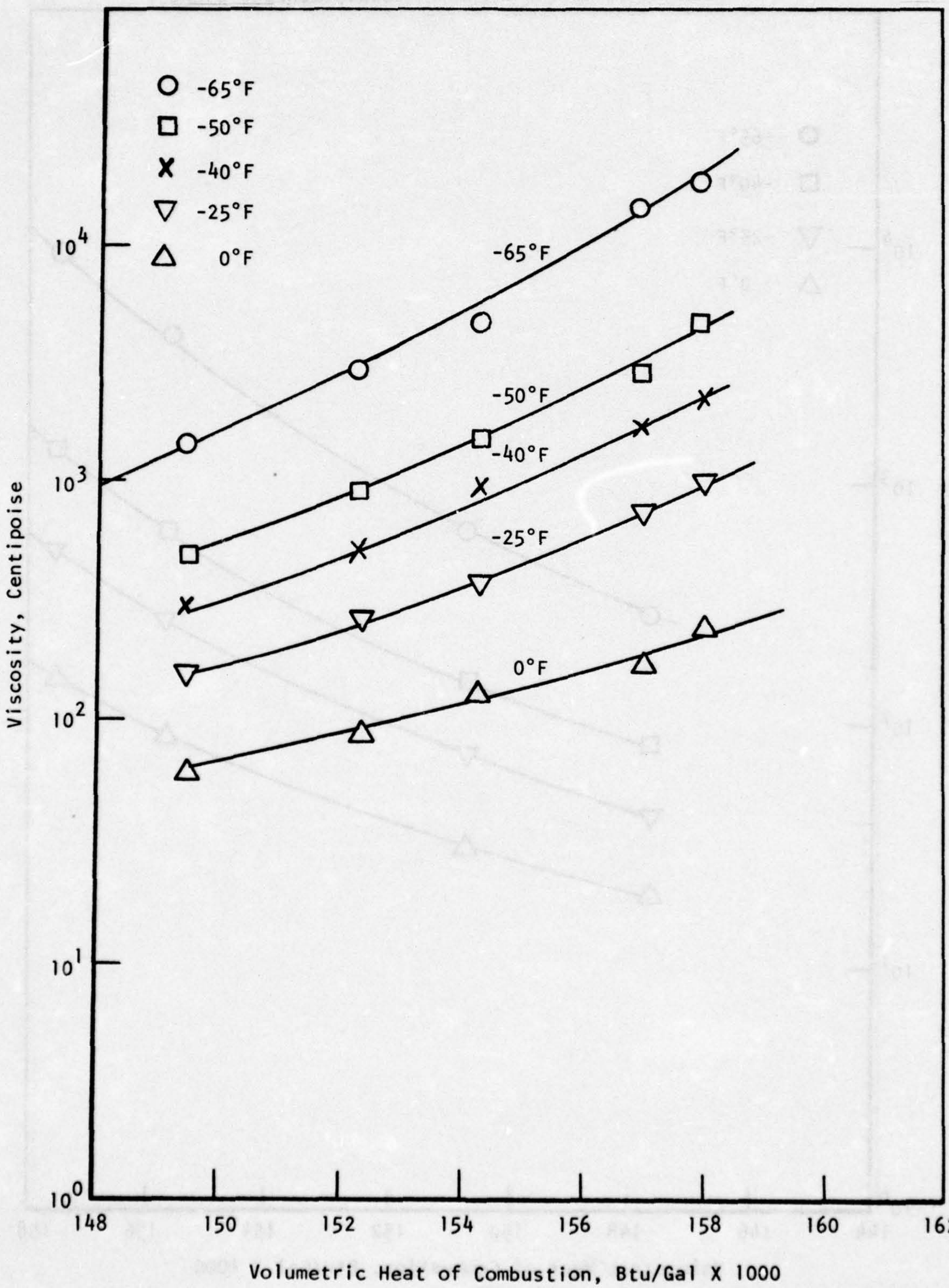


FIGURE 18. Viscosity at Various Temperatures vs. Volumetric Heat of Combustion for Shelldyne-H/Isobutylbenzene Blends.

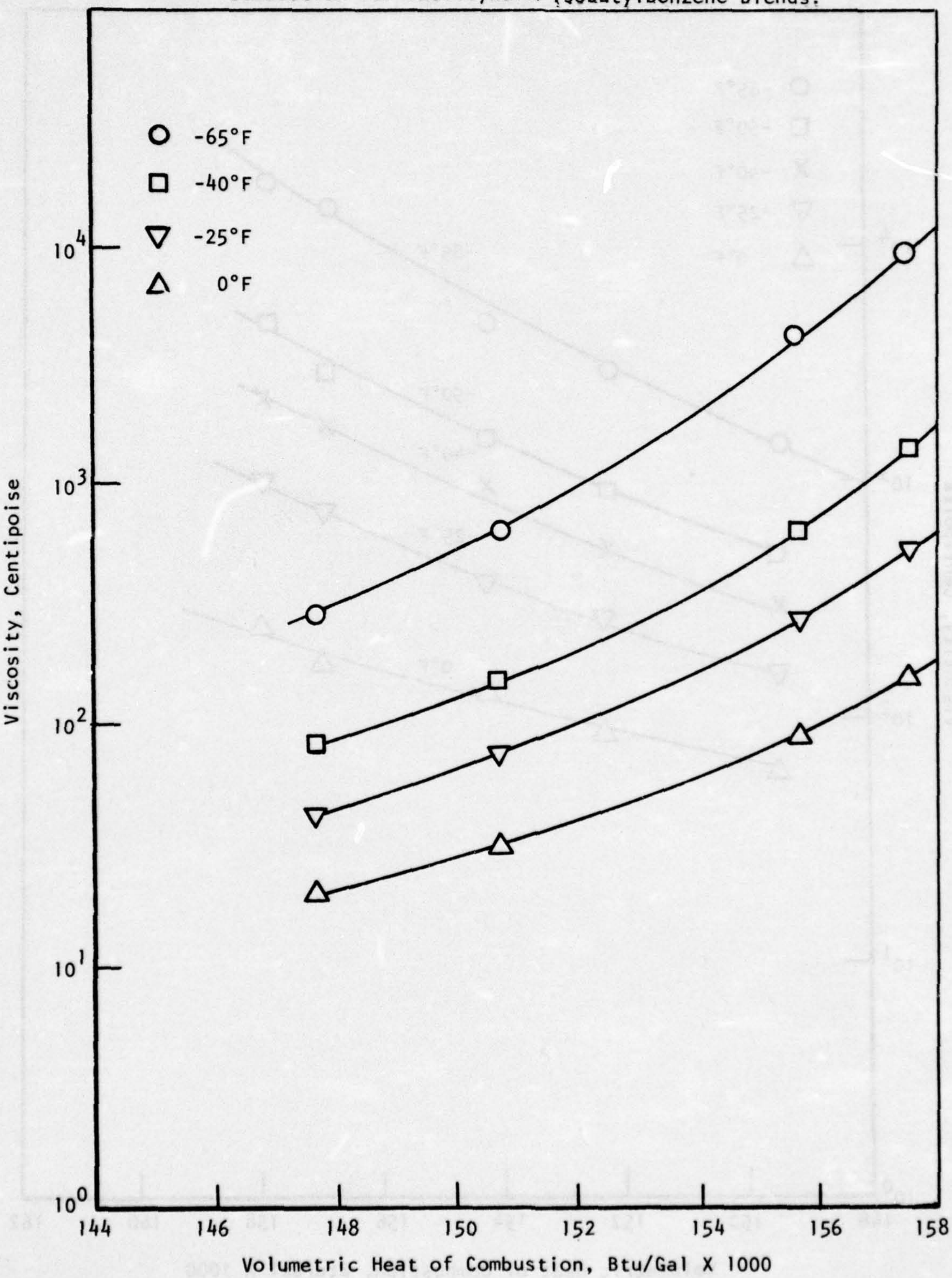


FIGURE 19. Viscosity at -65°F for Various Diluent/Shelldyne-H® Blends and Their Effect on Volumetric Heat of Combustion

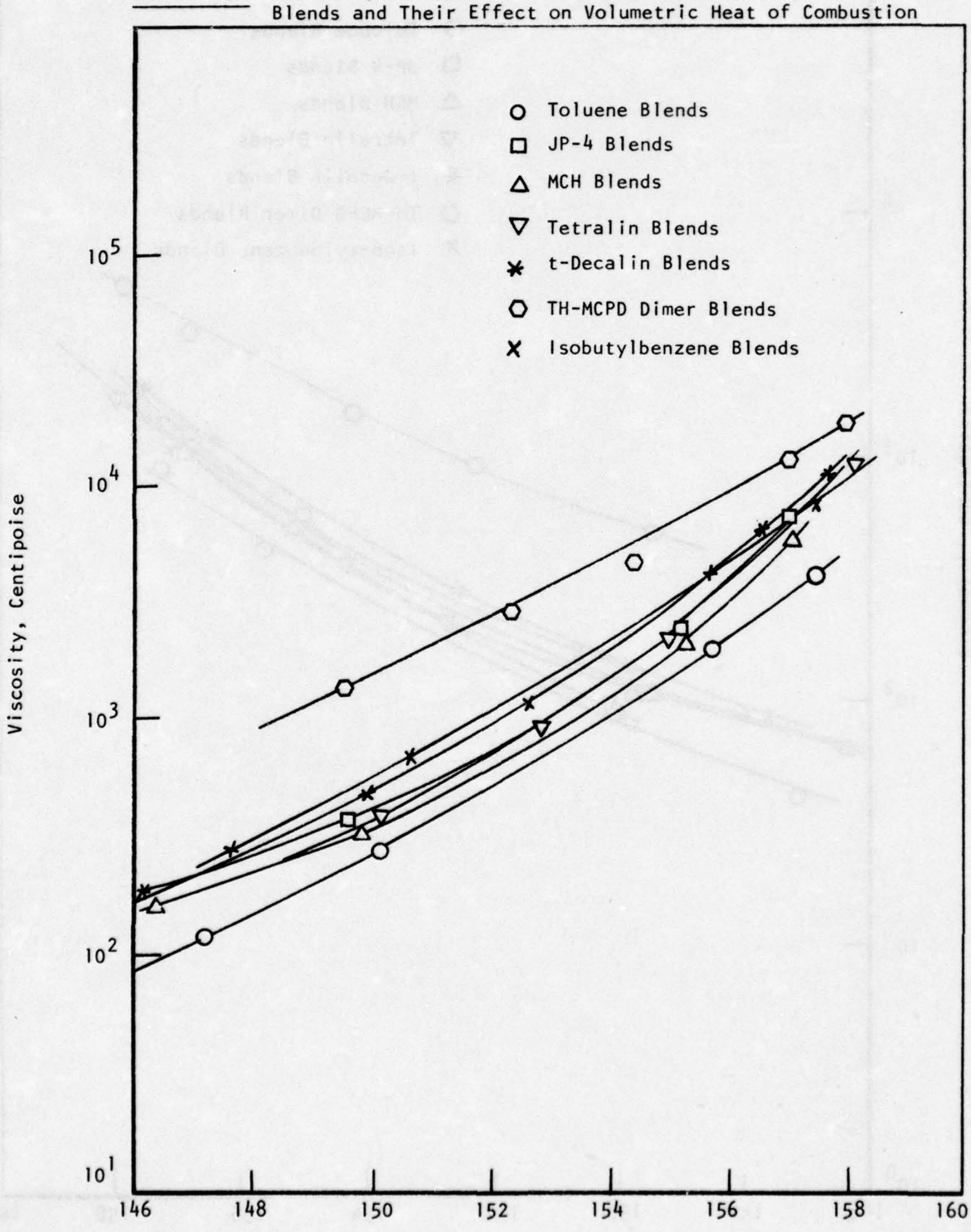
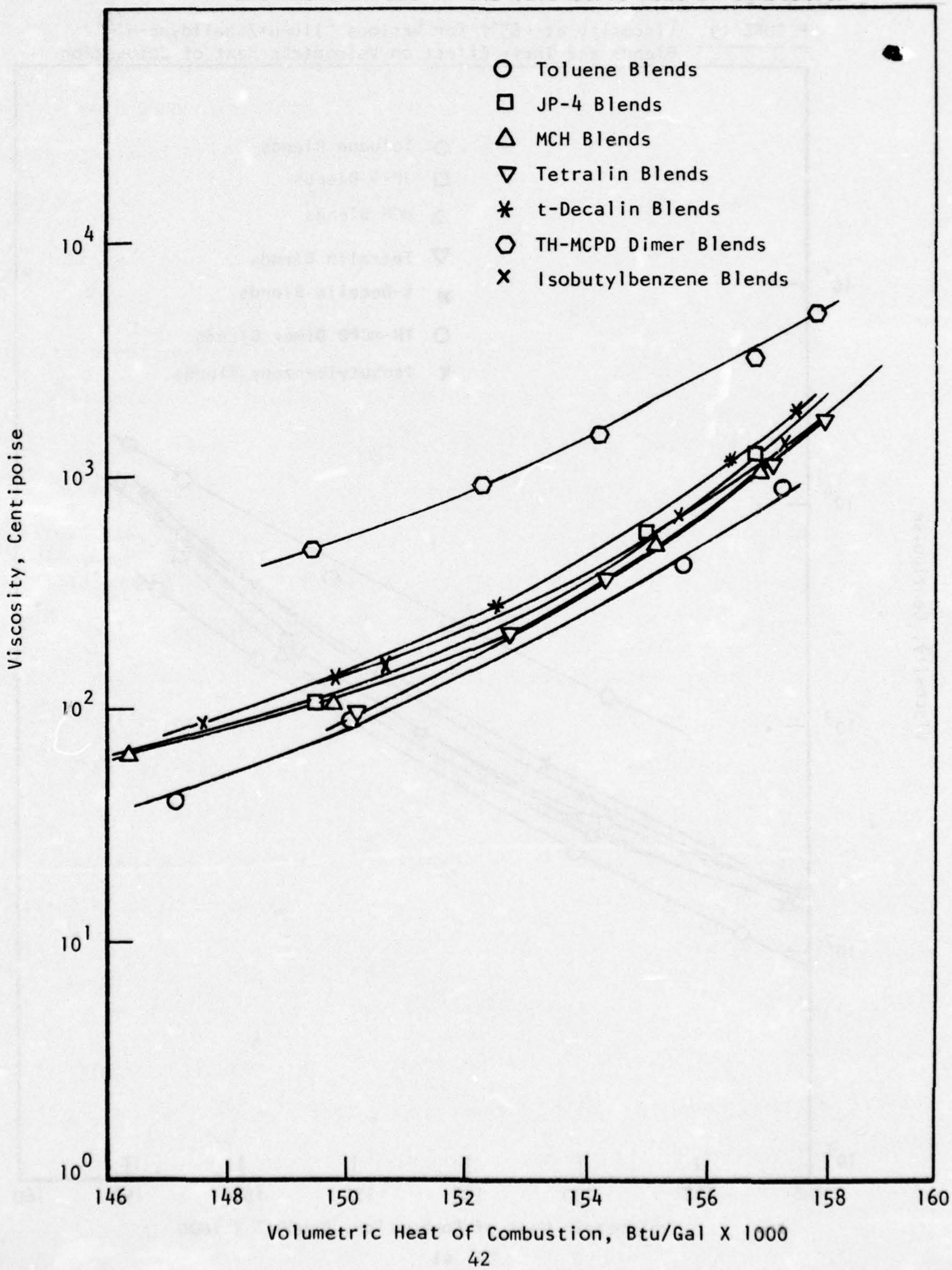


FIGURE 20. Viscosity at -40°F for Various Diluent/Shelldyne-H® Blends and Their Effect on the Volumetric Heat of Combustion



is similar to what it was at -65°F. Based on the low temperature, high volumetric energy criteria, toluene blends are best, with the TH-MCPD dimer being the poorest of the diluents tested; the remainder of the diluents fall in between these extremes with regard to these criteria.

As stated previously, Shelldyne-H® has the most desirable density and volumetric heating value of any hydrocarbons which will remain a liquid down to -65°F. However, these characteristics are overshadowed by the high viscosity of the materials at sub-zero conditions. The reference batch of Shelldyne-H® (Lot #11410-103) used in this program had viscosities at -65°F of 31,457 centipoise and at -40°F of 3092 centipoise. These values represent problems to the designer of a missile fuel system and engine. If 500 to 1000 centipoise fluids are feasible in a system, the test blends offer attractive options to the designer. Using the test data acquired in this program and the heats of combustion calculated in Appendix F, these data tabulated in Tables VIII, IX, X and XI were developed. These tables list the blends which would have viscosities of 500 or 1000 centipoise at -65°F and -40°F and also the approximate heat of combustion of each blend. In order to compare these blends with Shelldyne-H® and JP-4, the percentages of the volumetric heats of combustion of the blends with regard to these fuels are also indicated.

In Table VIII, all the blends produce 25% more energy than JP-4 and come within 93% of the energy of pure Shelldyne-H®; this effect is significant since the viscosity at -65°F is reduced by a factor of 31. The 18% toluene-82% Shelldyne-H® blends has approximately 97.2% of the volumetric

energy of pure Shelldyne-H® and 130.2% more energy than the JP-4 reference material. Table IX lists the blends that have a viscosity of 500 centipoise at -65°F, together with the approximated heats of combustion and their relation to the reference fuels. Here again, the blends have energies within 8% of Shelldyne-H® and at least 23% more than JP-4. Tables X and XI further exploit the potential available from the fuel blends if the lower temperature limit for specifying fuels is raised. In these tables the viscosity limits of 1000 and 500 centipoise are evaluated at -40°F. Again the toluene blends are most effective; but the other blends with the exception of the TH-MCPD blends are within a percent or two of the energy level of Shelldyne-H®.

Other properties should be considered by the designer in making a selection as to which test blends best suits his application. One such factor is volatility. For high altitude air launched applications, a volatile fuel might be required; therefore, blends of toluene, MCH, and JP-4 would be preferred. For shipboard and submarine applications, where 140°F falshpoint fuels are required, the blends of isobutylbenzene, trans-decalin, tetralin and TH-methylcyclopentadiene dimer are most attractive. Other characteristic fuel properties such as stability, compatibility, combustibility and toxicity p robably do not vary with these blends; therefore, they wuld not influence which blend a designer might select.

TABLE VIII

The Heat of Combustion (Vol.) of Various Diluent Shelldyne-H® Blends which have Viscosities of 1000 Centipoise at -65°F.

Diluent	Vol. % (60°F)	ΔH_c Btu/Gal	ΔH_c % Shelldyne-H®	ΔH_c % of JP-4
Toluene	18	154,000	97.2	130.2
MCH	19.5	153,550	96.9	129.8
JP-4	20	153,100	96.6	129.4
IBB	24.8	152,100	96.0	128.6
t-Decalin	30.5	152,050	95.9	128.5
Tetralin	35.5	153,000	96.5	129.3
TH-MCPD Dimer	60.5	148,300	93.6	125.3

TABLE IX

The Heat of Combustion (Vol.) of Various Diluent Shelldyne-H® Blends which have Viscosities of 500 Centipoise at -65°F.

Diluent	Vol. % (60°F)	ΔH_c Btu/Gal	ΔH_c % Shelldyne-H®	ΔH_c % of JP-4
Toluene	24.3	151,900	95.8	128.4
MCH	25.5	151,550	95.6	128.1
JP-4	26.3	150,900	95.2	127.5
IBB	32.5	149,800	94.5	126.6
t-Decalin	39.5	149,900	94.6	126.7
Tetralin	47.2	151,000	95.3	127.6
TH-MCPD	73.5	146,000	92.1	123.4

TABLE X

The Heat of Combustion (Vol) of Various Diluent Shelldyne-H® Blends which have Viscosities of 100 Centipoise at -40°F.

Diluent	Vol. % (60°F)	ΔH_c Btu/Gal	ΔH_c % Shelldyne-H®	ΔH_c % of JP-4
Toluene	6.5	157,800	99.4	133.4
MCH	8.0	157,200	99.2	132.9
JP-4	9.3	156,800	98.9	132.5
IBB	8.8	156,900	99.0	132.6
t-Decalin	12.0	156,500	98.7	132.3
Tetralin	11.0	157,250	99.2	132.9
TH-MCPD Dimer	35.0	152,900	96.5	129.2

TABLE XI

The Heat of Combustion (Vol) of Various Diluent Shelldyne-H® Blends which have Viscosities of 500 Centipoise at -40°F.

Diluent	Vol. % (60°F)	ΔH_c Btu/Gal	ΔH_c % Shelldyne-H®	ΔH_c % of JP-4
Toluene	10.7	156,400	98.7	132.2
MCH	13.0	155,450	98.1	131.4
JP-4	13.8	155,200	97.9	131.2
IBB	14.8	155,100	97.9	131.1
t-Decalin	20.0	154,550	97.5	130.6
Tetralin	20.5	155,550	98.1	131.5
TH-MCPD Dimer	38.5	152,300	96.1	128.7

SECTION VII
CONCLUSIONS

It is evident that a serious option for modifying RJ-5 is through blending with thinner (and less dense) hydrocarbons. There are many available materials which can significantly reduce viscosity without causing enormous energy reductions. These materials have, for the most part, differing physical and chemical characteristics which might make one more attractive than others for a particular system. Such characteristics as volatility and saturation are affected by blending and will ultimately aid in choosing the desired blend.

The major conclusion that can be drawn from this effort is that considerable progress is possible in the high density missile fuel area through the blending of hydrocarbon components. Present high density fuels (i.e., RJ-4, RJ-5) can be tailored to yield properties which are more adaptable to system design and yet have significantly more volumetric energy than conventional fuels (i.e., JP-4, JP-5, Jet A. Jet A-1, etc.). Blending should be an acceptable method for "customizing" a fuel since conventional fuels are normally blends of hundreds of different hydrocarbons which, individually, have properties quite different from the blend, but in mixture produce an optimized fuel.

A specific conclusion from this effort is that, on a basis of its improved low temperature viscosity coupled with resulting volumetric heating values, toluene is the best diluent for Shelldyne-H®. However, when considering other characteristics such as volatility, other materials such as methylcyclo-

hexane, tetralin, isobutylbenzene, decalin and even JP-4, might be more desirable. TH-MCPD dimer (RJ-4) is not considered a good blending component with Shelldyne-H® because it does not give much relief in viscosity and its viscosity-heat of combustion relationship is not as good as the other materials tested.

During the past several years, AFAPL has been cooperating with the Air Launched Cruise Missile (ALCM) System Program Office (SPO) in developing a high energy fuel[3,30]. This fuel currently is a tertiary blend of Shelldyne-H®, methylcyclohexane, and TH-MCPD; a final specification (JP-9) will be issued shortly. This specification is a result of the blending program at this laboratory.

SECTION VIII
RECOMMENDATIONS

The results of this program should be very encouraging to engineers interested in obtaining more range in volume limited systems. Present fuel specifications such as RJ-4 and RJ-5 have deficiencies which can be altered appreciably by blending with other hydrocarbons. The system designer should be aware of the possible fuel options available to him and the fact the Air Force and Navy have fuel development capabilities which could aid in modifying and establishing new fuel specifications for new and unique systems. The cooperative effort, cited previously between ALCM and AFAPL which led to the JP-9 class of fuels is an example of a fuel tailored for a particular system through close coordination and cooperation between fuel systems, engine and fuel development engineers[3, 30]. This type of cooperation is recommended in any effort where conventional fuels do not quite achieve performance goals and where compromises are not permitted.

APPENDIX A

CALCULATIONS FOR DETERMINING VISCOSITY ON THE CONE AND PLATE VISCOMETER

Consider the cone and plate configuration as used on the Weissenberg Rheogoniometer as diagrammed in Figure A-1.

Where,

α = Angle of cone (degrees)

β = Angular rotation of the platen (radians/sec)

d = Diameter of the platens (cm)

The rate of shear at any point on the plate or cone is given by:

$$\sigma = (\text{Angular velocity in radians/sec})/\tan\alpha \qquad \text{(A-1)}$$

For small cone angles, (A-1) becomes:

$$\sigma = \frac{180}{\pi}\,(\beta/\alpha)\ (\text{sec}^{-1}) \qquad \text{(A-2)}$$

(A-2) can be rearranged to give the following:

$$\sigma = \frac{360}{\alpha t}\ (\text{sec}^{-1}) \qquad \text{(A-3)}$$

$$\text{where } t = {}^{2\pi}/_{\beta}\ (\text{sec/rev}) \qquad \text{(A-4)}$$

The value of t can be determined from the reciprocal of the set speed on the lower platen.

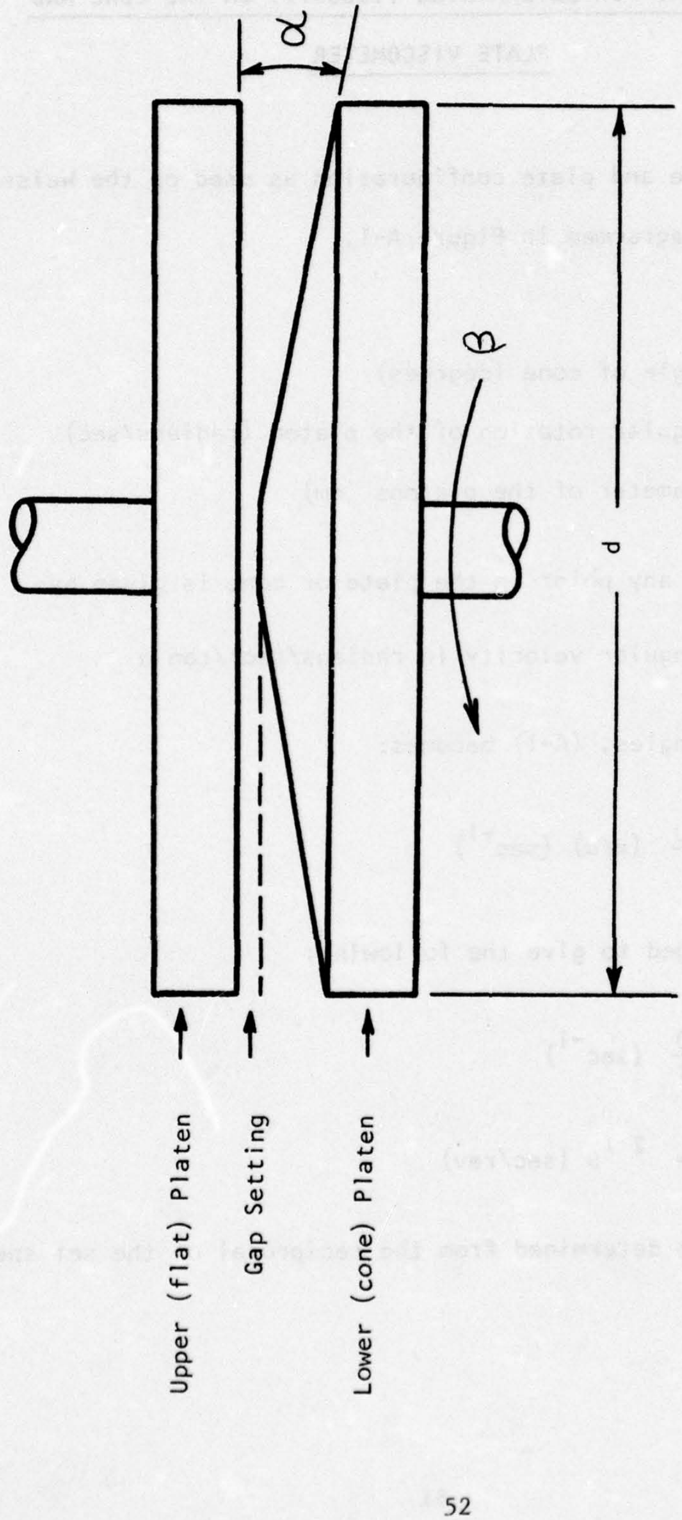


FIGURE A-1. Cone and Plate Viscometer Schematic

Next, the torque measured on the top platen of radius R (cm) is given by:

$$T = \int_0^R 2\pi\, \mu_\alpha\, \sigma r^2\, dr \qquad \text{(A-5)}$$

where μ_α = Apparent viscosity

r = Distance from center of platen to any point on the platen, cm

(A-5) can be integrated over the entire radius of the platen (R) to give the following:

$$T = \frac{2}{3}\, \pi\, \mu_\alpha\, \sigma\, R^3 \text{ (dyne-cm)} \qquad \text{(A-6)}$$

μ_α, the apparent viscosity or viscosity coefficient, is expressed in many different dimensions. For our work, the poise or centipoise is most often used. One poise is equal to a dyne-second per cm^2. Since the work described in this report deals only with Newtonian fluids, the apparent viscosity (μ_α) is the viscosity of the material and is constant for all shear rates and shear stresses. Therefore, we will use:

$$\mu = \mu_\alpha \qquad \text{(A-7)}$$

Incorporating (A-7) into (A-6) and rearranging, one will obtain:

$$\mu = (^3/_2)\ (T)\ /\ (\pi\ \sigma\ R^3) \text{ (poise)} \qquad \text{(A-8)}$$

Incorporating (A-3) into (A-8) one obtains

$$\mu\ (3\alpha\ tT)/(720\ \pi\ R^3) \qquad \text{(A-9}$$

or $$\mu = (\alpha t T)/(30\ \pi\ d^3) \qquad \text{(A-10)}$$

where $d = 2R$

or $R^3 = (1/8)d^3$

(A-10) can be further simplified to:

$$\mu = \frac{\alpha t T}{94.25\ d^3} \qquad \text{(A-11)}$$

In the Weissenberg Rheogoniometer, the torque on the upper platen can be related to the movement of the upper platen and a constant which relates displacement to torque:

$$T = \Delta m\ K_T \qquad \text{(A-12)}$$

where Δm = Movement of torsion head transducer, microns

K_T = Calculated torsion bar constant, dyne-cm/micron

The torsion bar used in our program was the lightest available and was calibrated to have a constant of 1.851×10^1 dyne-cm of torque per micron of displacement. Therefore, for our program, the torque on the upper platen was given as:

$$T = 18.51\ \Delta m \text{ (dyne-cm)} \qquad \text{(A-13)}$$

For the test program, only the 5 cm (diameter) platens were used with the 2° 0'22" cone angle. Therefore, by substituting (A-13) in (A-11) and incorporating the values for the α and d^3 one obtains the following expression for viscosity:

$$\mu = 3.1519 \times 10^{-3}\ (t\ \Delta m) \qquad \text{(A-14)}$$

The period, t (time required for the revolution of the bottom platen), is readily obtained from the gearbox settings which offers 60 easily selected output speeds in equal ratio steps of $10^{-0.1}$ (1:1.259 reduction). The manufacturer supplies a table of rotation speeds (RPM) and t (sec/rev) for the 60 possible gear box settings. In our work, we used only the settings which corresponded to 167.0, 16.7 and 1.67 sec/revolution. Since the fluids were all Newtonian, their viscosities were independent of shear rate and platen speeds were selected to give acceptable readings on the 0 to 200 micron range. It was felt that this range was the optimum from an accuracy viewpoint.

Other calculations of interest in this effort were those for determining shear stress and shear rate. It is well known that for Newtonian fluids, the shear stress is directly proportional to the shear rate. The proportionality constant is commonly called the viscosity coefficient or merely the viscosity:

$$S = \mu \sigma$$

where S = shear stress ($^{dyne}/_{cm^2}$) (A15)

For the calculations involved in our research, (A-15) can be rearranged using (A-14) and (A-3) to obtain

$$S = 0.5657 \, \Delta m \; (dyne/cm^2) \tag{A16}$$

Equation (A-16) is only applicable for the 5 cm diameter platen using the 6/26 torsion bar and is independent of α. Other size platens and torsion bars will require modification of the constant.

The shear rate can be determined from (A-3) for the 2° 0'22" cone angle of our specimen:

$$\sigma = (179.4517)/t \ (\mathrm{sec}^{-1}) \qquad \text{(A-17)}$$

The constant in this expression will change with different cone angles, α:

In summary, the calculations required in this effort where the 5 cm diameter platens, 2°0'22" cone angle and 6/26 (identifying number, K_T = 18.51 dyne-cm) torsion bar were used as follows:

Viscosity (from A-14) $\mu = 3.1519 \times 10^{-3}$ (t Δm) (poise)

Shear rate (from A-17) $\sigma = (179.4517)/t$ (sec^{-1})

Shear stress (from A-16) $S = 0.5657\ \Delta m$ $(^{\mathrm{dynes}}/_{\mathrm{cm}^2})$

APPENDIX B

THERMAL EXPANSION OF THE WEISSENBERG RHEOGONIOMETER

From Appendix A it was noted that the cone on the bottom platen was truncated (Figure A-1). It is vital for the sake of accuracy that the point of the cone should just touch the center of the flat platen. This, however, would disturb the reading of the torque so the point of the cone is truncated to prevent this interference. This gives negligible error[26]; the torque produced at the center of the platen being immeasurable, but it is vitally important to adjust the gap between the truncated cone of the bottom platen and the flat surface of the top platen as accurately as possible. The imaginary top of the cone should touch the center of the upper platen. The amount of truncation for the Platen Nr 1141 (2° 0' 22") used in this program was 91 microns; this was determined by the manufacturer and engraved on the back of the cone.

Since this program involved making measurements at temperatures other than ambient, it was necessary to determine the effect of temperature change on the test equipment and the gap between the platens. The instruction manual[26] reported that the gap between platens would close up by about 0.69 microns for each °F that the platens are heated. The exact change, of course, would differ depending on the size of the torsion bar platen holder and test platens. Therefore, a program was formulated to determine the amount of adjustment necessary to keep the gap setting constant at each temperature tested. Since we used only the Nr 1141 platen, we needed to maintain the gap setting at 91 microns.

A unique feature of the R-17 Weissenberg Rheogoniometer is the micrometer gap setting knob that is provided. The exact procedure for gap setting is outlined in Reference 26. Since our testing would include measurements to -75°F, we had to determine the adjustment necessary to assure the correct gap setting. A description of the procedure used follows. The 5 cm platens (Nr 1141 and Nr 865) were put onto the instrument. The alignment procedures were followed and the gap was set at 91 microns at 75°F. Using the normal cooling technique of cold nitrogen gas, the temperature of the test chamber was lowered 150°F to -75°F, and the test platens were emptied. By using the gap setting knob micrometer dial, the gap setting at this lower temperature could be determined. The chamber was cold soaked for one hour and the gap was found to have expanded to 221 microns. The gap was reset at 221 microns at -75°F and the temperature was raised to -50°F where the gap setting had decreased to 198 microns. This gap was reset and the temperature was raised to -25°F where the gap was checked. This procedure was followed at each temperature until ambient was reached. The summary of the temperature effect on gap setting is as follows in Table B-1.

A plot of gap setting adjustment as a function of temperature is shown in Figure B-1. This plot was used to determine the appropriate adjustment in gap setting for each test temperature in this program. From our experimentation it was found that the gap closed an average of approximately 0.867 microns per °F which agrees rather closely with the manual's estimate of 0.69 microns/°F.

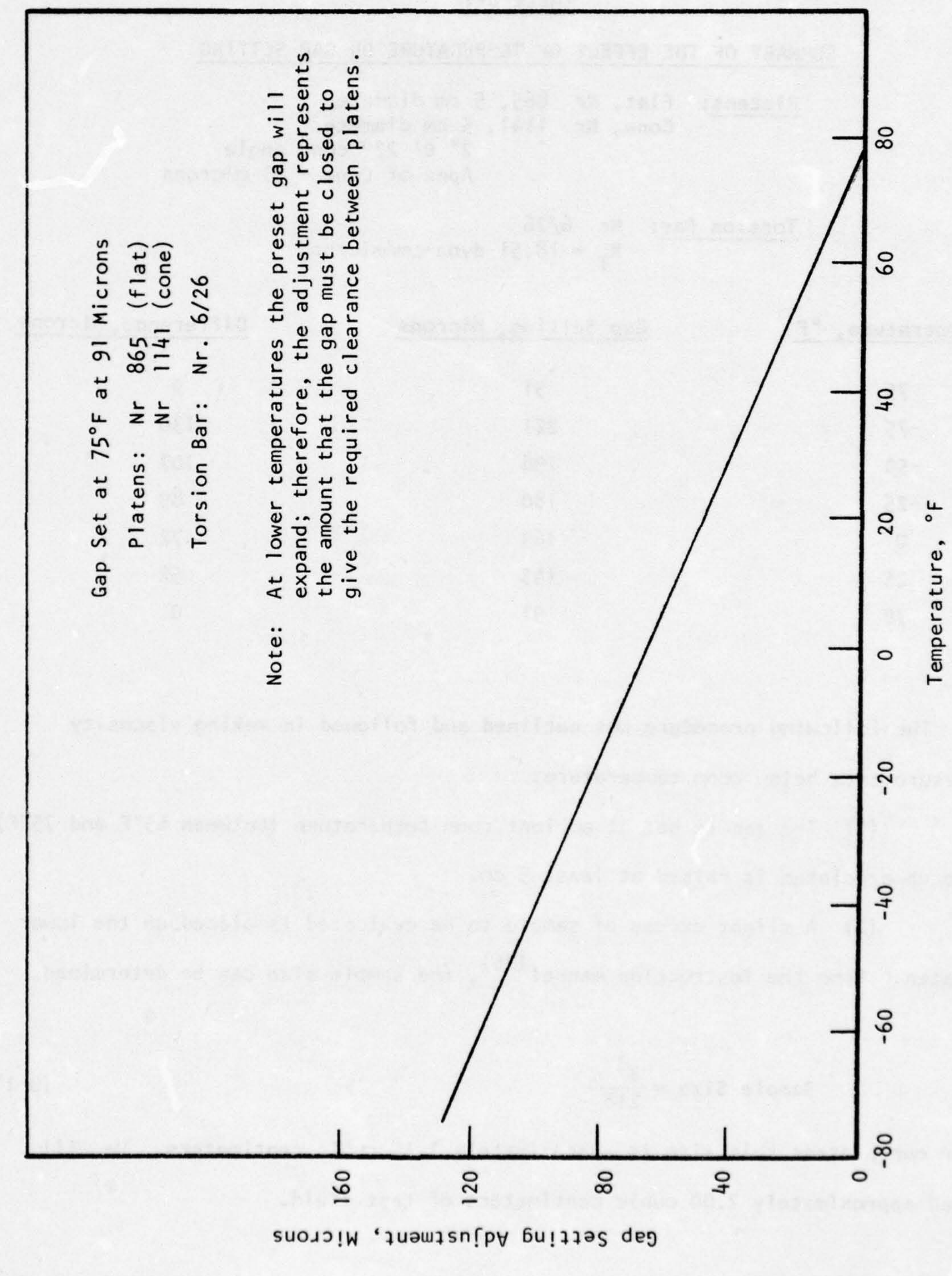


FIGURE B-1. Gap Setting Adjustment at Various Temperatures

TABLE B-1

SUMMARY OF THE EFFECT OF TEMPERATURE ON GAP SETTING

Platens: Flat, Nr 865, 5 cm diameter
Cone, Nr 1141, 5 cm diameter
2° 0' 22" cone angle
Apex of Cone - 91 microns

Torsion Bar: Nr 6/26
K_T = 18.51 dyne-cm/micron

Temperature, °F	Gap Setting, Microns	Difference, Microns
75	91	0
-75	221	130
-50	198	107
-25	180	89
0	163	72
25	143	52
70	91	0

The following procedure was outlined and followed in making viscosity measurements below room temperature:

(1) The gap is set at ambient room temperature (between 65°F and 75°F). The upper platen is raised at least 5 cm.

(2) A slight excess of sample to be evaluated is placed on the lower platen. From the instruction manual[26], the sample size can be determined.

$$\text{Sample Size} = \frac{d^3 \alpha}{218} \qquad \text{(B-1)}$$

For our platens this size is approximately 1.15 cubic centimeters. We will load approximately 2.00 cubic centimeters of test fluid.

(3) The upper platen is lowered, but only until the top surface of the sample is contacted.

(4) Using the cold nitrogen gas system, the chamber temperature is lowered to the lowest test temperature. The upper platen is then lowered until it comes to the correct stop.

(5) After 15 minutes at this test temperature, the gap is adjusted as indicated by the chart on Figure B-1 or by calculations, the reduction necessary from the fact that the gap will open by 0.867 microns per °F.

(6) After an additional 15 minutes, determine the viscosity at the shear rate of interest. The procedure for determining viscosities is outlined in Appendix C and should be followed for each determination at each temperature of interest.

(7) After another 15 minute interval, Step (6) is repeated. The results are compared and if the results are within 1 meter indication, continue on to Step (8). If the results are not within 1 meter indication, Step (7) is repeated until two consecutive readings are within 1 meter indication.

(8) Proceed to the next highest temperature; repeat Steps (5) through (7).

(9) Continue running until viscosities are determined at the required shear rates and temperatures.

The test temperatures in this program were -65, -50, -40, -25, 0, 25, 50 and 70°F.

APPENDIX C

VISCOSITY DETERMINATION PROCEDURES FOR THE R17 WEISSENBERG RHEOGONIOMETER

Following is the procedure for obtaining viscosity determination on the Model R17 Weissenberg Rheogoniometer.

(1) The operator should be familiar with the "Weissenberg Rheogoniometer Model R17 Instruction Manual" which is obtainable from Sangamo Controls, Ltd. through Technidyne Corporation, Louisville, Kentucky.

(2) The transducer meters and servo system amplifiers should be switched on 15 minutes or more before testing is to be carried out to allow them to reach their operating temperature and stablize.

(3) Each transducer meter is calibrated before starting the test series. The range is put on "CAL" and the "SET CALIBRATION" adjustment altered so that the transducer meter needle is exactly on the full scale mark.

(4) The appropriate plates and torsion bars are fitted as outlined in the instruction manual.

(5) The required gearbox speed is selected, using the setting as determined from Table C-1.

(6) The gap is set as outlined in detail in the manual. Ambient room temperature should be in the range of 65°F-75°F.

(7) The upper platen is raised at least 5 cm and the sample is loaded. The procedures outlined in Appendix B, with reduced test temperatures, should be followed at this point.

NOTE: During the test the least sensitive range of the transducer meters should be chosen to start with and the more sensitive ranges selected, as necessary, to prevent possible damage to the equipment.

(8) At each determination, the transducer meters and recorders should be set at the correct range.

(9) The rotation motor should be started and the brake/drive unit should be switched to "DRIVE".

(10) The operator should record the following information in his record book: the date, time, test specimen, gap setting, temperature, gap setting adjustment, transmission setting.

(11) The readings on the transducer meter should be noted and recorded in the record book.

(12) The test is completed and the brake/drive unit is switched to "BRAKE".

(13) If the test is to be repeated, Steps (9) through (12) are repeated.

When changing test temperatures, the procedures in Appendix B should be consulted.

TABLE C-1

ROTATIONAL SPEEDS - 3600 R.P.M. MOTOR

GEARBOX SETTING		ROTATION		OSCILLATION	
RIGHT	LEFT	R.P.M	SEC/REV	C.P.S.	SEC/CYCLE
0.0	0.0	7.20×10^{2}	0.84×10^{-1}	6.00×10	1.67×10^{-2}
	0.1	5.72×10^{2}	1.05×10^{-1}	4.76×10	2.10×10^{-2}
	0.2	4.54×10^{2}	1.32×10^{-1}	3.80×10	2.63×10^{-2}
	0.3	3.60×10^{2}	1.67×10^{-1}	3.02×10	3.31×10^{-2}
	0.4	2.88×10^{2}	2.09×10^{-1}	2.40×10	4.17×10^{-2}
0.5	0.0	2.28×10^{2}	2.64×10^{-1}	18.96	5.27×10^{-2}
	0.1	1.808×10^{2}	3.32×10^{-1}	15.12	6.61×10^{-2}
	0.2	1.438×10^{2}	4.17×10^{-1}	12.00	8.33×10^{-2}
	0.3	1.142×10^{2}	.53	9.52	10.50×10^{-2}
	0.4	9.08×10^{1}	.66	7.58	13.19×10^{-2}

TABLE C-1

ROTATIONAL SPEEDS - 3600 R.P.M. MOTOR

GEARBOX SETTING		ROTATION		OSCILLATION	
RIGHT	LEFT	R.P.M	SEC/REV	C.P.S.	SEC/CYCLE
1.0	0.0	7.20 X 10	0.83	6.00	1.67×10^{-1}
	0.1	5.72 X 10	1.05	4.76	2.10×10^{-1}
	0.2	4.54 X 10	1.32	3.80	2.63×10^{-1}
	0.3	3.60 X 10	1.67	3.02	3.31×10^{-1}
	0.4	2.88 X 10	2.09	2.40	4.17×10^{-1}
1.5	0.0	2.28 X 10	2.64	1.896	5.27×10^{-1}
	0.1	1.808 X 10	3.32	1.512	6.61×10^{-1}
	0.2	1.438 X 10	4.17	1.200	8.33×10^{-1}
	0.3	1.142 X 10	5.25	0.952	10.50×10^{-1}
	0.4	9.08	6.60	0.758	13.19×10^{-1}

TABLE C-1

ROTATIONAL SPEEDS - 3600 R.P.M. MOTOR

GEARBOX SETTING		ROTATION		OSCILLATION	
RIGHT	LEFT	R.P.M	SEC/REV	C.P.S.	SEC/CYCLE
2.0	0.0	7.20	8.3	0.600	1.67
	0.1	5.72	10.5	0.476	2.10
	0.2	4.54	13.2	0.380	2.63
	0.3	3.60	16.7	0.302	3.31
	0.4	2.88	20.9	0.240	4.17
2.5	0.0	2.28	2.64 X 10	1.896×10^{-1}	5.27
	0.1	1.808	3.32 X 10	1.512×10^{-1}	6.61
	0.2	1.438	4.17 X 10	1.200×10^{-1}	8.33
	0.3	1.142	5.25 X 10	0.952×10^{-1}	10.50
	0.4	0.908	6.60 X 10	0.758×10^{-1}	13.19

TABLE C-1

ROTATIONAL SPEEDS - 3600 R.P.M. MOTOR

GEARBOX SETTING		ROTATION		OSCILLATION	
RIGHT	LEFT	R.P.M	SEC/REV	C.P.S.	SEC/CYCLE
3.0	0.0	7.20×10^{-1}	8.3×10	0.600×10^{-1}	1.67×10^{1}
	0.1	5.72×10^{-1}	10.5×10	0.476×10^{-1}	2.10×10^{1}
	0.2	4.54×10^{-1}	13.2×10	0.380×10^{-1}	2.63×10^{1}
	0.3	3.60×10^{-1}	16.7×10	0.302×10^{-1}	3.31×10^{1}
	0.4	2.88×10^{-1}	20.9×10	0.240×10^{-1}	4.17×10^{1}
3.5	0.0	2.28×10^{-1}	2.64×10^{2}	1.896×10^{-2}	5.27×10^{1}
	0.1	1.808×10^{-1}	3.32×10^{2}	1.512×10^{-2}	6.61×10^{1}
	0.2	1.438×10^{-1}	4.17×10^{2}	1.200×10^{-2}	8.33×10^{1}
	0.3	1.142×10^{-1}	5.25×10^{2}	0.952×10^{-2}	10.50×10^{1}
	0.4	0.908×10^{-1}	6.60×10^{2}	0.758×10^{-2}	13.19×10^{1}

TABLE C-1

ROTATIONAL SPEEDS - 3600 R.P.M. MOTOR

GEARBOX SETTING		ROTATION		OSCILLATION	
RIGHT	LEFT	R.P.M	SEC/REV	C.P.S.	SEC/CYCLE
4.0	0.0	7.20×10^{-2}	8.3×10^{2}	0.600×10^{-2}	1.67×10^{2}
	0.1	5.72×10^{-2}	10.5×10^{2}	0.476×10^{-2}	2.10×10^{2}
	0.2	4.54×10^{-2}	13.2×10^{2}	0.380×10^{-2}	2.63×10^{2}
	0.3	3.60×10^{-2}	16.7×10^{2}	0.302×10^{-2}	3.31×10^{2}
	0.4	2.88×10^{-2}	20.9×10^{2}	0.240×10^{-2}	4.17×10^{2}
4.5	0.0	2.28×10^{-2}	2.64×10^{3}	1.896×10^{-3}	5.27×10^{2}
	0.1	1.808×10^{-2}	3.32×10^{3}	1.512×10^{-3}	6.61×10^{2}
	0.2	1.438×10^{-2}	4.17×10^{3}	1.200×10^{-3}	8.33×10^{2}
	0.3	1.142×10^{-2}	5.25×10^{3}	0.952×10^{-3}	10.50×10^{2}
	0.4	0.908×10^{-2}	6.60×10^{3}	0.758×10^{-3}	13.19×10^{2}

TABLE C-1

ROTATIONAL SPEEDS - 3600 R.P.M. MOTOR

GEARBOX SETTING		ROTATION		OSCILLATION	
RIGHT	LEFT	R.P.M	SEC/REV	C.P.S.	SEC/CYCLE
5.0	0.0	7.20×10^{-3}	8.3×10^{3}	0.600×10^{-3}	1.67×10^{3}
	0.1	5.72×10^{-3}	10.5×10^{3}	0.476×10^{-3}	2.10×10^{3}
	0.2	4.54×10^{-3}	13.2×10^{3}	0.380×10^{-3}	2.63×10^{3}
	0.3	3.60×10^{-3}	16.7×10^{3}	0.302×10^{-3}	3.31×10^{3}
	0.4	2.88×10^{-3}	20.9×10^{3}	0.240×10^{-3}	4.17×10^{3}
5.5	0.0	2.28×10^{-3}	2.64×10^{4}	1.896×10^{-4}	5.27×10^{3}
	0.1	1.808×10^{-3}	3.32×10^{4}	1.512×10^{-4}	6.61×10^{3}
	0.2	1.438×10^{-3}	4.17×10^{4}	1.200×10^{-4}	8.33×10^{3}
	0.3	1.142×10^{-3}	5.25×10^{4}	0.952×10^{-4}	10.50×10^{3}
	0.4	0.908×10^{-3}	6.60×10^{4}	0.758×10^{-4}	13.19×10^{3}

APPENDIX D

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA SHEETS

The viscosity data were generated using the procedures outlined in Appendices B and C and the calculation presented in Appendix A. Table D-1 lists the sample number of each fluid tested in this program and identifies its chemical composition on a volume percentage basis.

Table D-2 is the data which was taken on the rheogoniometer and converted into viscosities and shear rates. Each data point in Table D-2 usually represents the average of two determinations. In addition, the project record book and associated page number where these data are recorded is also noted in this table. As an example "RB Nr 55422 (21 and 23)" would indicate that these data can be found in Record Book 55422 on pages 21 and 23.

TABLE D-1

COMPOSITION OF FUEL BLENDS EVALUATED ON WEISSENBERG RHEOGONIOMETER

SAMPLE NUMBER	CHEMICAL COMPOSITION, VOL. %
SH	Shelldyne-H®(SH), Batch Nr LR-11410-103
SH A	Shelldyne-H® unknown Batch number
SH B	Shelldyne-H® Batch Nr LR-10318-174, Barrel #2
SH C	Shelldyne-H® Batch Nr LR-10318-174, Barrel #1
SH D	Shelldyne-H®, Batch Nr LR-10704-45
SH-1	94.9% SH, 5.1% toluene
SH-2	87.7% SH, 12.3% toluene
SH-3	70.9% SH, 29.1% toluene
SH-4	64.9% SH, 35.1% toluene
SH-5 & SH-5A	46.3% SH, 53.7% toluene
SH-6	93.1% SH, 6.9% JP-4
SH-7	86.5% SH, 13.5% JP-4
SH-8 & SH-8A	68.1% SH, 31.9% JP-4
SH-9	56.9% SH, 43.1% JP-4
SH-10	41.6% SH, 68.4% JP-4
SH-11	93.1% SH, 6.9% methylcyclohexane (MCH)
SH-12	86.5% SH, 13.5% MCH
SH-13	68.1% SH, 31.9% MCH
SH-14	56.9% SH, 43.1% MCH
SH-15	41.6% SH, 58.4% MCH
SH-16	94.5% SH, 5.5% tetralin
SH-17	89.1% SH, 10.9% tetralin
SH-18	73.2% SH, 26.8% tetralin
SH-19	62.9% SH, 37.1 tetralin
SH-20	47.7% SH, 52.3% tetralin
SH-22A	45.2% SH, 54.8% cis-decalin
SH-26A	45.2% SH, 54.8% trans-decalin
SH-28A	100% TH-methylcyclopentadiene dimer (TH-MCPD)
SH-29A	94.3% SH, 5.7% TH-MCPD
SH-30A	88.5% SH, 11.5% TH-MCPD
SH-31A	72.2% SH, 27.8% TH-MCPD
SH-32A	61.7% SH, 38.3% TH-MCPD
SH-33A	46.3% SH, 53.7% TH-MCPD
SH-34	94.1% SH, 5.9% trans-decalin
SH-35	88.1% SH, 11.9% trans-decalin
SH-36	71.0% SH, 29.0% trans-decalin
SH-37	60.3% SH, 39.7% trans-decalin
SH-38	45.2% SH, 54.8% mixed decalin isomers
SH-39	93.8% SH, 6.2% isobutylbenzene (IBB)
SH-40	87.7% SH, 12.3% IBB
SH-41	70.4% SH, 29.6% IBB
SH-42	59.7% SH, 40.3% IBB
SH-43	44.2% SH, 55.8% IBB

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22" Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55422 (21 and 23)

Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures Millivolts	Test Temperatures °F	Gap Setting Adjustment Microns	Transmission Left	Transmission Right	t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
SH-1	-1.93	-65.2	-123	0.3	3.0	167.0	85.3	1.075	4,489.9
SH-1	-1.65	-50.1	-110	0.3	3.0	167.0	28.5	1.075	1,500.1
SH-1	-1.47	-40.4	-102	0.3	3.0	167.0	16.0	1.075	842.2
SH-1	-1.18	-25.2	- 88	0.3	2.0	16.7	65.0	10.746	342.1
SH-1	-0.67	0	- 66	0.3	2.0	16.7	22.0	10.746	115.8
SH-1	-0.14	25.3	- 44	0.3	2.0	16.7	9.75	10.746	51.3
SH-1	0.40	50.3	- 22	0.3	1.0	1.67	48.0	107.456	25.3
SH-1	0.84	70.3	- 4	0.3	1.0	1.67	34.0	107.456	17.9
SH-4	-1.93	-65.2	-123	0.3	2.0	16.7	21.0	10.746	110.5
SH-4	-1.65	-50.1	-110	0.3	2.0	16.7	11.0	10.746	57.9
SH-4	-1.47	-40.4	-102	0.3	1.0	1.67	76.0	107.456	40.0
SH-4	-1.18	-25.2	- 88	0.3	1.0	1.67	47.5	107.456	25.0
SH-4	-0.67	0	- 66	0.3	1.0	1.67	26.0	107.456	13.7
SH-4	-0.14	25.3	- 44	0.3	1.0	1.67	19.0	107.456	10.0
SH-4	0.40	50.3	- 22	0.3	1.0	1.67	14.0	107.456	7.4
SH-4	0.84	70.3	- 4	0.3	1.0	1.67	13.0	107.456	6.8

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22'' Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55422 (20 and 22)

Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

TABLE D-2 (Cont'd)

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-2	-1.93	-65.2	-123	0.3	3.0	167	37.0	1.075	1.947.5
SH-2	-1.65	-50.1	-110	0.3	3.0	167	12.63	1.075	665.8
SH-2	-1.47	-40.4	-102	0.3	2.0	16.7	72.5	10.746	381.6
SH-2	-1.18	-25.2	- 88	0.3	2.0	16.7	36.0	10.746	189.5
SH-2	-0.67	0	- 66	0.3	2.0	16.7	13.38	10.746	70.4
SH-2	-0.14	25.3	- 44	0.3	1.0	1.67	65.0	107.456	34.2
SH-2	0.40	50.3	- 22	0.3	1.0	1.67	37.5	107.456	19.7
SH-2	0.84	70.3	- 4	0.3	1.0	1.67	26.5	107.456	13.9
SH-3	-1.93	-65.2	-123	0.3	2.0	16.7	55.0	10.746	289.5
SH-3	-1.65	-50.1	-110	0.3	2.0	16.7	26.3	10.746	138.4
SH-3	-1.47	-40.4	-102	0.3	2.0	16.7	17.5	10.746	92.1
SH-3	-1.18	-25.2	- 88	0.3	2.0	16.7	10.25	10.746	54.0
SH-3	-0.67	0	- 66	0.3	1.0	1.67	46.5	107.456	24.5
SH-3	-0.14	25.3	- 44	0.3	1.0	1.67	30.0	107.456	15.8
SH-3	0.40	50.3	- 22	0.3	1.0	1.67	19.8	107.456	10.4
SH-3	0.84	70.3	- 4	0.3	1.0	1.67	16.5	107.456	8.7

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm; Cone Angle 2° 0' 22''; Gap Setting 91 Microns

Flat Nr 865; Cone Nr 1141; RB # 55422 (24 and 25)

Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

TABLE D-2 (Cont'd)

Sample Number	Test Temperatures Millivolts	°F	Gap Setting Adjustment Microns	Transmission Left	Right	t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
SH-5	-1.93	-65.2	-123	0.3	2.0	16.7	14.0	10.746	73.7
SH-5	-1.93	-65.2	-123	0.3	1.0	1.67	141.0	107.456	74.2
SH-5	-1.65	-50.1	-110	0.3	1.0	1.67	76.0	107.456	40.0
SH-5	-1.47	-40.4	-102	0.3	1.0	1.67	56.3	107.456	29.6
SH-5	-1.18	-25.2	- 88	0.3	1.0	1.67	37.0	107.456	19.5
SH-5	-0.67	0	- 66	0.3	1.0	1.67	21.3	107.456	11.2
SH-5	-0.14	25.3	- 44	0.3	1.0	1.67	17.0	107.456	8.9
SH-5	0.40	50.3	- 22	0.3	1.0	1.67	13.13	107.456	6.9
SH-5	0.84	70.3	- 4	0.3	1.0	1.67	12.0	107.456	6.3
SH-6	-1.93	-65.2	-123	0.3	3.0	167	145.5	1.075	7.658.6
SH-6	-1.65	-50.1	-110	0.3	3.0	167	41.5	1.075	2.184.4
SH-6	-1.47	-40.4	-102	0.3	3.0	167	21.5	1.075	1.131.7
SH-6	-1.18	-25.2	- 88	0.3	3.0	167	8.5	1.075	447.4
SH-6	-1.18	-25.2	- 88	0.3	2.0	16.7	85.5	10.746	450.0
SH-6	-0.67	0	- 66	0.3	2.0	16.7	28.0	10.746	147.4
SH-6	-0.14	25.3	- 44	0.3	2.0	16.7	11.75	10.746	61.8
SH-6	0.40	50.3	- 22	0.3	1.0	1.67	57.0	107.456	30.0
SH-6	0.84	70.3	- 4	0.3	1.0	1.67	38.0	107.456	20.0

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22" Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55422 (26 and 27)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-7	-1.93	-65.2	-123	0.3	3.0	167	52.5	1.075	2,763.4
SH-7	-1.65	-50.1	-110	0.3	3.0	167	16.88	1.075	888.5
SH-7	-1.47	-40.4	-102	0.3	3.0	167	10.25	1.075	539.5
SH-7	-1.18	-25.2	- 88	0.3	2.0	16.7	46.5	10.746	244.8
SH-7	-1.47	-40.4	-102	0.3	2.0	16.7	102.0	10.746	536.9
SH-7	-0.67	0	- 66	0.3	2.0	16.7	16.5	10.746	86.9
SH-7	-0.14	25.3	- 44	0.3	1.0	1.67	74.0	107.456	39.0
SH-7	0.40	50.3	- 22	0.3	1.0	1.67	40.5	107.456	21.3
SH-7	0.84	70.3	- 4	0.3	1.0	1.67	27.5	107.456	14.4
SH-8A	-1.93	-65.2	-123	0.3	2.0	16.7	64.0	10.746	336.9
SH-8A	-1.65	-50.1	-110	0.3	2.0	16.7	27.63	10.746	145.4
SH-8A	-1.47	-40.4	-102	0.3	2.0	16.7	18.5	10.746	97.4
SH-8A	-1.18	-25.2	- 88	0.3	2.0	16.7	10.75	10.746	56.6
SH-8A	-0.67	0	- 66	0.3	1.0	1.67	50.0	107.456	26.3
SH-8A	-0.14	25.3	- 44	0.3	1.0	1.67	31.3	107.456	16.5
SH-8A	0.40	50.3	- 22	0.3	1.0	1.67	20.0	107.456	10.5
SH-8A	0.84	70.3	- 4	0.3	1.0	1.67	15.5	107.456	8.2

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22'' Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55422 (28 and 29)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-9	-1.93	-65.2	-123	0.3	2.0	16.7	30.0	10.746	157.9
SH-9	-1.65	-50.1	-110	0.3	2.0	16.7	15.38	10.746	81.0
SH-9	-1.47	-40.4	-102	0.3	2.0	16.7	10.75	10.746	56.6
SH-9	-1.47	-40.4	-102	0.3	2.0	1.67	105.0	107.456	55.4
SH-9	-1.18	-25.2	- 88	0.3	1.0	1.67	65.0	107.456	34.2
SH-9	-0.67	0	- 66	0.3	1.0	1.67	33.0	107.456	17.4
SH-9	-0.14	25.3	- 44	0.3	1.0	1.67	20.3	107.456	10.7
SH-9	0.40	50.3	- 22	0.3	1.0	1.67	13.55	107.456	7.1
SH-10	-1.93	-65.2	-123	0.3	2.0	16.7	10.5	10.746	55.3
SH-10	-1.65	-50.1	-110	0.3	1.0	1.67	60.5	107.456	31.8
SH-10	-1.47	-40.4	-102	0.3	1.0	1.67	44.0	107.456	23.2
SH-10	-1.18	-25.2	- 88	0.3	1.0	1.67	29.0	107.456	15.3
SH-10	-0.67	0	- 66	0.3	1.0	1.67	17.13	107.456	9.0
SH-10	-0.14	25.3	- 44	0.3	1.0	1.67	12.68	107.456	6.7
SH-10	0.40	50.3	- 22	0.3	1.0	1.67	9.25	107.456	4.9
SH-10	0.84	70.3	4	0.3	1.0	1.67	7.5	107.456	3.9

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm   Cone Angle 2° 0' 22''   Gap Setting 91 Microns

Flat Nr 865   Cone Nr 1141   RB # 55423(1) and 55422(30)

TABLE D-2 (Cont'd)   Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-11	-1.93	-65.2	-123	0.3	3.0	167	115.0	1.075	6,053.1
SH-11	-1.65	-50.1	-110	0.3	3.0	167	34.3	1.075	1,805.4
SH-11	-1.47	-40.4	-102	0.3	3.0	167	18.4	1.075	968.5
SH-11	-1.18	-25.2	- 88	0.3	3.0	167	7.75	1.075	407.9
SH-11	-1.18	-25.2	- 88	0.3	2.0	16.7	75.5	10.746	397.4
SH-11	-0.67	0	- 66	0.3	2.0	16.7	25.5	10.746	134.2
SH-11	-0.14	25.3	- 44	0.3	2.0	16.7	11.0	10.746	57.9
SH-11	0.40	50.3	- 22	0.3	1.0	1.67	55.0	107.456	29.0
SH-11	0.84	70.3	- 4	0.3	1.0	1.67	37.0	107.456	19.5
SH-12	-1.93	-65.2	-123	0.3	3.0	167	42.5	1.075	2,237.0
SH-12	-1.65	-50.1	-110	0.3	3.0	167	15.88	1.075	835.9
SH-12	-1.47	-40.4	-102	0.3	2.0	16.7	91.0	10.746	479.0
SH-12	-1.18	-25.2	- 88	0.3	2.0	16.7	43.3	10.746	227.9
SH-12	-0.67	0	- 66	0.3	2.0	16.7	15.75	10.746	82.9
SH-12	-0.14	25.3	- 44	0.3	1.0	1.67	75.0	107.456	39.5
SH-12	0.40	50.3	- 22	0.3	1.0	1.67	41.5	107.456	21.8
SH-12	0.84	70.3	- 4	0.3	1.0	1.67	29.0	107.456	15.3

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm   Cone Angle 2° 0' 22"   Gap Setting 91 Microns

Flat Nr 865   Cone Nr 1141   RB # 55423 (4 and 5)

TABLE D-2 (Cont'd)   Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-13	-1.93	-65.2	-123	0.3	2.0	16.7	61.0	10.746	321.1
SH-13	-1.65	-50.1	-110	0.3	2.0	16.7	29.3	10.746	154.2
SH-13	-1.47	-40.4	-102	0.3	2.0	16.7	19.88	10.746	104.6
SH-13	-1.18	-25.2	- 88	0.3	2.0	16.7	11.25	10.746	59.2
SH-13	-1.18	-25.2	- 38	0.3	1.0	1.67	112.0	107.456	66.3
SH-13	-0.67	0	- 66	0.3	1.0	1.67	56.5	107.456	29.7
SH-13	-0.14	25.3	- 44	0.3	1.0	1.67	40.0	107.456	21.1
SH-13	0.40	50.3	- 22	0.3	1.0	1.67	25.0	107.456	13.2
SH-13	0.84	70.3	- 4	0.3	1.0	1.67	20.0	107.456	10.5
SH-14	-1.93	-65.2	-123	0.3	2.0	16.7	31.8	10.746	167.4
SH-14	-1.65	-50.1	-110	0.3	2.0	16.7	16.75	10.746	88.2
SH-14	-1.47	-40.4	-102	0.3	2.0	16.7	12.0	10.746	63.2
SH-14	-1.18	-25.2	- 88	0.3	2.0	16.7	7.5	10.746	39.5
SH-14	-1.18	-25.2	- 88	0.3	2.0	1.67	80.0	107.456	42.1
SH-14	-0.67	0	- 66	0.3	2.0	1.67	43.0	107.456	22.6
SH-14	-0.14	25.3	- 44	0.3	2.0	1.67	28.0	107.456	14.7
SH-14	0.40	50.3	- 22	0.3	2.0	1.67	18.5	107.456	9.7
SH-14	0.84	70.3	- 4	0.3	2.0	1.67	15.0	107.456	7.9

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm — Cone Angle 2° 0' 22" — Gap Setting 91 Microns

Flat Nr 865 — Cone Nr 1141 — RB # 55423 (7 and 8)

Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-15	-1.93	-65.2	-123	0.3	1.0	1.67	80.0	107.456	42.1
SH-15	-1.65	-50.1	-110	0.3	1.0	1.67	50.0	107.456	26.3
SH-15	-1.47	-40.4	-102	0.3	1.0	1.67	39.3	107.456	20.7
SH-15	-1.18	-25.2	- 88	0.3	1.0	1.67	28.0	107.456	14.7
SH-15	-0.67	0	- 66	0.3	1.0	1.67	15.5	107.456	8.2
SH-15	-0.14	25.3	- 44	0.3	1.0	1.67	8.63	107.456	4.5
SH-15	0.40	50.3	- 22	0.3	1.0	1.67	6.5	107.456	3.4
SH-15	0.84	70.3	- 4	0.3	1.0	1.67	5.75	107.456	3.0
SH-16	-1.93	-65.2	-123	0.3	3.0	167	250.0	1.075	13,159.1
SH-16	-1.65	-50.1	-110	0.3	3.0	167	74.5	1.075	3,921.4
SH-16	-1.47	-40.4	-102	0.3	3.0	167	31.0	1.075	1,631.7
SH-16	-1.18	-25.2	- 88	0.3	3.0	167	12.5	1.075	658.0
SH-16	-0.67	0	- 66	0.3	2.0	16.7	36.0	10.746	189.5
SH-16	-0.14	25.3	- 44	0.3	2.0	16.7	13.5	10.746	71.1
SH-16	0.40	50.3	- 22	0.3	1.0	1.67	62.5	107.456	32.9
SH-16	0.84	70.3	- 4	0.3	1.0	1.67	39.0	107.456	20.5

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm — Cone Angle 2° 0' 22" — Gap Setting 91 Microns

Flat Nr 865 — Cone Nr 1141 — RB # 55423 (9 and 10)

TABLE D-2 (Cont'd) — Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-17	-1.93	-65.2	-123	0.3	3.0	167.0	151.5	1.075	7,974.4
SH-17	-1.65	-50.1	-110	0.3	3.0	167.0	41.0	1.075	2,158.1
SH-17	-1.47	-40.4	-102	0.3	3.0	167.0	19.8	1.075	1,042.2
SH-17	-1.18	-25.2	- 88	0.3	3.0	167.0	8.1	1.075	426.4
SH-17	-1.18	-25.2	- 88	0.3	2.0	16.7	80.5	10.746	423.7
SH-17	-0.67	0	- 66	0.3	2.0	16.7	25.3	10.746	133.2
SH-17	-0.14	25.3	- 44	0.3	2.0	16.7	10.5	10.746	55.3
SH-17	0.40	50.3	- 22	0.3	2.0	16.7	50.0	10.746	26.3
SH-17	0.84	70.3	- 4	0.3	2.0	16.7	32.0	10.746	16.8
SH-18	-1.93	-65.2	-123	0.3	3.0	167.0	32.5	1.075	1,710.7
SH-18	-1.65	-50.1	-110	0.3	3.0	167.0	12.63	1.075	664.8
SH-18	-1.47	-40.4	-102	0.3	2.0	16.7	62.5	10.746	329.0
SH-18	-1.18	-25.2	- 88	0.3	2.0	16.7	29.0	10.746	152.6
SH-18	-0.67	0	- 66	0.3	2.0	16.7	11.13	10.746	58.6
SH-18	-0.67	0	- 66	0.3	1.0	1.67	110.0	107.456	58.4
SH-18	-0.14	25.3	- 44	0.3	1.0	1.67	48.0	107.456	25.3
SH-18	0.40	50.3	- 22	0.3	1.0	1.67	27.0	107.456	14.2
SH-18	0.84	70.3	- 4	0.3	1.0	1.67	18.5	107.456	9.7

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm   Cone Angle 2° 0' 22''   Gap Setting 91 Microns

Flat Nr 865   Cone Nr 1141   RB # 55423 (12 and 13)

TABLE D-2 (Cont'd)   Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-19	-1.93	-65.2	-123	0.3	3.0	167.0	18.0	1.075	947.5
SH-19	-1.65	-50.1	-110	0.3	2.0	16.7	65.0	10.746	342.1
SH-19	-1.47	-40.4	-102	0.3	2.0	16.7	40.5	10.746	213.2
SH-19	-1.18	-25.2	- 88	0.3	2.0	16.7	19.3	10.746	101.6
SH-19	-0.67	0	- 66	0.3	1.0	1.67	66.0	107.456	34.7
SH-19	-0.14	25.3	- 44	0.3	1.0	1.67	34.0	107.456	17.9
SH-19	0.40	50.3	- 22	0.3	1.0	1.67	21.0	107.456	11.1
SH-19	0.84	70.3	- 4	0.3	1.0	1.67	13.88	107.456	7.3
SH-20	-1.93	-65.2	-123	0.3	2.0	16.7	75.0	10.746	394.8
SH-20	-1.65	-50.1	-110	0.3	2.0	16.7	30.0	10.746	157.9
SH-20	-1.47	-40.4	-102	0.3	2.0	16.7	17.5	10.746	92.1
SH-20	-1.18	-25.2	- 88	0.3	1.0	1.67	90.5	107.456	47.6
SH-20	-0.67	0	- 66	0.3	1.0	1.67	40.0	107.456	21.1
SH-20	-0.14	25.3	- 44	0.3	1.0	1.67	22.5	107.456	11.8
SH-20	0.40	50.3	- 22	0.3	1.0	1.67	13.5	107.456	7.1
SH-20	0.84	70.3	- 4	0.3	1.0	1.67	9.25	107.456	4.9

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22" Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55423 (16 and 21)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-5A	-1.93	-65.2	-123	0.3	1.0	1.67	52.8	107.456	27.8
SH-5A	-1.65	-50.1	-110	0.3	1.0	1.67	35.8	107.456	18.8
SH-5A	-1.47	-40.4	-102	0.3	1.0	1.67	26.0	107.456	13.7
SH-5A	-1.18	-25.2	- 88	0.3	1.0	1.67	18.5	107.456	9.7
SH-5A	-0.67	0	- 66	0.3	1.0	1.67	10.8	107.456	5.7
SH-5A	-0.14	25.3	- 44	0.3	1.0	1.67	7.5	107.456	3.9
SH-5A	0.40	50.3	- 22	0.3	1.0	1.67	5.75	107.456	3.0
SH-5A	0.84	70.3	- 4	0.3	1.0	1.67	5.0	107.456	2.6
SH-28A	-1.93	-65.2	-123	0.3	2.0	16.7	93.8	10.746	493.7
SH-28A	-1.65	-50.1	-110	0.3	2.0	16.7	23.0	10.746	121.1
SH-28A	-1.47	-40.4	-102	0.3	2.0	16.7	14.5	10.746	76.3
SH-28A	-1.18	-25.2	- 88	0.3	1.0	1.67	82.5	107.456	43.4
SH-28A	-0.67	0	- 66	0.3	1.0	1.67	40.8	107.456	21.5
SH-28A	-0.14	25.3	- 44	0.3	1.0	1.67	23.3	107.456	12.3
SH-28A	0.40	50.3	- 22	0.3	1.0	1.67	14.13	107.456	7.4
SH-28A	0.84	70.3	- 4	0.3	1.0	1.67	10.0	107.456	5.3

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm — Cone Angle 2° 0' 22" — Gap Setting 91 Microns

Flat Nr 865 — Cone Nr 1141 — RB # 55424 (25, 27)

TABLE D-2 (Cont'd) — Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH	-1.93	-65.2	-123	0.3	3.0	167.0	600.0	1.075	31,581.8
SH	-1.65	-50.1	-110	0.3	3.0	167.0	140.0	1.075	7,369.1
SH	-1.47	-40.4	-102	0.3	3.0	167.0	60.5	1.075	3,184.5
SH	-1.18	-25.2	- 88	0.3	3.0	167.0	20.8	1.075	1,074.8
SH	-0.67	0	- 66	0.3	2.0	16.7	53.8	10.746	283.2
SH	-0.14	25.3	- 44	0.3	2.0	16.7	18.8	10.746	99.0
SH	0.40	50.3	- 22	0.3	1.0	1.67	91.0	107.456	47.9
SH	0.84	70.3	- 4	0.3	1.0	1.67	51.0	107.456	26.8
SH	-1.93	-65.2	-123	0.3	3.0	167.0	585.5	1.075	30,818.6
SH	-1.65	-50.1	-110	0.3	3.0	167.0	136.3	1.075	7,174.3
SH	-1.47	-40.4	-102	0.3	3.0	167.0	59.0	1.074	3,105.5
SH	-1.18	-25.2	- 88	0.3	3.0	167.0	20.8	1.075	1,094.8
SH	-0.67	0	- 66	0.3	2.0	16.7	52.5	10.746	276.3
SH	-0.14	25.3	- 44	0.3	2.0	16.7	19.5	10.746	102.6
SH	0.40	50.3	- 22	0.3	1.0	1.67	91.0	107.456	47.9
SH	0.84	70.3	- 4	0.3	1.0	1.67	52.0	107.456	27.4

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22'' Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55423 (24 and 25)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-30A	-1.93	-65.2	-123	0.3	3.0	167.0	270.0	1.075	14,211.9
SH-30A	-1.65	-50.1	-110	0.3	3.0	167.0	56.5	1.075	2,974.0
SH-30A	-1.47	-40.4	-102	0.3	3.0	167.0	31.5	1.075	1,658.1
SH-30A	-1.18	-25.2	- 88	0.3	3.0	167.0	13.5	1.075	710.6
SH-30A	-0.67	0	- 66	0.3	2.0	16.7	32.0	10.746	168.4
SH-30A	-0.14	25.3	- 44	0.3	2.0	16.7	13.0	10.746	68.4
SH-30A	-0.14	25.3	- 44	0.3	1.0	1.67	128.0	107.456	67.4
SH-30A	0.40	50.3	- 22	0.3	1.0	1.67	65.0	107.456	34.2
SH-30A	0.84	70.3	- 4	0.3	1.0	1.67	39.0	107.456	20.5
SH-31A	-1.93	-65.2	-123	0.3	3.0	167.0	89.0	1.075	4,684.7
SH-31A	-1.65	-50.1	-110	0.3	3.0	167.0	28.5	1.075	1,500.1
SH-31A	-1.47	-40.4	-102	0.3	3.0	167.0	17.8	1.075	936.9
SH-31A	-1.18	-25.2	- 88	0.3	2.0	16.7	68.0	10.746	357.9
SH-31A	-0.67	0	- 66	0.3	2.0	16.7	23.8	10.746	125.3
SH-31A	-0.14	25.3	- 44	0.3	2.0	16.7	10.0	10.746	52.6
SH-31A	-0.14	25.3	- 44	0.3	1.0	1.67	100.0	107.456	52.6
SH-31A	0.40	50.3	- 22	0.3	1.0	1.67	46.0	107.456	24.2
SH-31A	0.84	70.3	- 4	0.3	1.0	1.67	30.0	107.456	15.8

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm | Cone Angle 2° 0' 22" | Gap Setting 91 Microns

Flat Nr 865 | Cone Nr 1141 | RB # 55423 (26 and 27)

TABLE D-2 (Cont'd) | Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures Millivolts	°F	Gap Setting Adjustment Microns	Transmission Left	Right	t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
SH-32A	-1.93	-65.2	-123	0.3	3.0	167.0	55.0	1.075	2,895.0
SH-32A	-1.65	-50.1	-110	0.3	3.0	167.0	17.0	1.075	894.8
SH-32A	-1.47	-40.4	-102	0.3	2.0	16.7	95.0	10.746	500.0
SH-32A	-1.18	-25.2	- 88	0.3	2.0	16.7	48.3	10.746	254.3
SH-32A	-0.67	0	- 66	0.3	2.0	16.7	16.8	10.746	88.4
SH-32A	-0.14	25.3	- 44	0.3	1.0	1.67	77.0	107.456	40.5
SH-32A	-0.40	50.3	- 22	0.3	1.0	1.67	38.5	107.456	20.3
SH-32A	0.84	70.3	- 4	0.3	1.0	1.67	25.5	107.456	13.4
SH-33A	-1.93	-65.2	-123	0.3	3.0	167.0	26.8	1.075	1,410.6
SH-33A	-1.65	-50.1	-110	0.3	3.0	167.0	9.38	1.075	493.7
SH-33A	-1.47	-40.4	-102	0.3	2.0	16.7	55.0	10.746	289.5
SH-33A	-1.65	-50.1	-110	0.3	2.0	16.7	93.0	10.746	489.5
SH-33A	-1.18	-25.2	- 88	0.3	2.0	16.7	28.3	10.746	149.9
SH-33A	-0.67	0	- 66	0.3	2.0	16.7	11.5	10.746	60.53
SH-33A	-0.67	0	- 66	0.3	1.0	1.67	110.0	107.456	58.4
SH-33A	-0.14	25.3	- 44	0.3	1.0	1.67	55.5	107.456	29.2
SH-33A	0.40	50.3	- 22	0.3	1.0	1.67	30.3	107.456	15.9
SH-33A	0.84	70.3	- 4	0.3	1.0	1.67	21.0	107.456	11.1

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm | Cone Angle 2° 0' 22" | Gap Setting 91 Microns

Flat Nr 865 | Cone Nr 1141 | RB # 55424 (7) and 55423 (28)

TABLE D-2 (Cont'd) | Torsion Bar Data: $K_T = 1.851 \times 10'$ Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-29A	-1.93	-65.2	-123	0.3	3.0	167.0	355.0	1.075	18,686.0
SH-29A	-1.65	-50.1	-110	0.3	3.0	167.0	85.0	1.075	4,474.1
SH-29A	-1.47	-40.4	-102	0.3	3.0	167.0	41.0	1.075	2,158.1
SH-29A	-1.18	-25.2	- 88	0.3	3.0	167.0	18.0	1.075	947.5
SH-29A	-0.67	0	- 66	0.3	2.0	16.7	44.5	10.746	234.2
SH-29A	-0.14	25.3	- 44	0.3	2.0	16.7	18.0	10.746	94.7
SH-29A	0.40	50.3	- 22	0.3	1.0	1.67	75.3	107.456	39.6
SH-29A	0.84	70.3	- 4	0.3	1.0	1.67	45.5	107.456	23.9
SH-22A	-1.93	-65.2	-123	0.3	2.0	16.7	86.0	10.746	452.7
SH-22A	-165	-50.1	-110	0.3	2.0	16.7	39.8	10.746	209.5
SH-22A	-1.47	-40.4	-102	0.3	2.0	16.7	26.3	10.746	138.4
SH-22A	-1.18	-25.2	- 88	0.3	2.0	16.7	14.5	10.746	76.3
SH-22A	-0.67	0	- 66	0.3	1.0	1.67	65.0	107.456	34.2
SH-22A	-0.14	25.3	- 44	0.3	1.0	1.67	34.0	107.456	17.9
SH-22A	0.40	50.3	- 22	0.3	1.0	1.67	20.8	107.456	10.9
SH-22A	0.84	70.3	- 4	0.3	1.0	1.67	14.0	107.456	7.4

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22'' Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55424 (9, 10)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-26A	-1.93	-65.2	-123	0.3	2.0	16.7	36.0	10.746	189.5
SH-26A	-1.65	-50.1	-110	0.3	2.0	16.7	18.0	10.746	94.7
SH-26A	-1.47	-40.4	-102	0.3	1.0	1.67	118.8	107.456	62.5
SH-26A	-1.18	-25.2	- 88	0.3	1.0	1.67	72.8	107.456	38.3
SH-26A	-0.67	0	- 66	0.3	1.0	1.67	36.5	107.456	19.2
SH-26A	-0.14	25.3	- 44	0.3	1.0	1.67	22.0	107.456	11.6
SH-26A	0.40	50.3	- 22	0.3	1.0	1.67	14.0	107.456	7.4
SH-26A	0.84	70.3	- 4	0.3	1.0	1.67	10.5	107.456	5.5
SH-37	-1.93	-65.2	-123	0.3	2.0	16.7	96.8	10.746	509.5
SH-37	-1.65	-50.1	-110	0.3	2.0	16.7	39.5	10.746	207.9
SH-37	-1.47	-40.4	-102	0.3	2.0	16.7	26.5	10.746	139.5
SH-37	-1.18	-25.2	- 88	0.3	2.0	16.7	15.0	10.746	79.0
SH-37	-0.67	0	- 66	0.3	1.0	1.67	64.0	107.456	33.7
SH-37	-0.14	25.3	- 44	0.3	1.0	1.67	35.8	107.456	18.8
SH-37	0.40	50.3	- 22	0.3	1.0	1.67	20.5	107.456	10.8
SH-37	0.84	70.3	- 4	0.3	1.0	1.67	14.5	107.456	7.6

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22" Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55424 (11, 13)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-36	-1.93	-65.2	-123	0.3	3.0	167.0	23.0	1.075	1,210.6
SH-36	-1.65	-50.1	-110	0.3	2.0	16.7	86.3	10.746	454.3
SH-36	-1.93	-65.2	-123	0.3	2.0	16.7	230.0	10.746	1,210.6
SH-36	-1.47	-40.4	-101	0.3	2.0	16.7	52.5	10.746	276.3
SH-36	-1.45	-39.3	-101	0.3	2.0	16.7	49.5	10.746	260.6
SH-36	-1.18	-25.2	- 88	0.3	2.0	16.7	27.8	10.746	146.3
SH-36	-0.67	0	- 66	0.3	1.0	1.67	102.0	107.456	53.7
SH-36	-0.14	25.3	- 44	0.3	1.0	1.67	50.0	107.456	26.3
SH-36	0.40	50.3	- 22	0.3	1.0	1.67	28.8	107.456	15.2
SH-36	0.84	70.3	- 4	0.3	1.0	1.67	21.0	107.456	11.1
SH-35	-1.93	-65.2	-123	0.3	3.0	167.0	116.0	1.074	6,105.8
SH-35	-1.65	-50.1	-110	0.3	3.0	167.0	38.0	1.075	2,000.2
SH-35	-1.47	-40.4	-101	0.3	3.0	167.0	19.3	1.074	1,015.9
SH-35	-1.18	-25.2	- 88	0.3	2.0	16.7	80.0	10.746	421.1
SH-35	-0.67	0	- 66	0.3	2.0	16.7	27.3	10.746	143.7
SH-35	-0.14	25.3	- 44	0.3	2.0	16.7	11.0	10.746	57.9
SH-35	-0.14	25.3	- 44	0.3	1.0	1.67	107.8	107.456	56.7
SH-35	+0.40	50.3	- 22	0.3	1.0	1.67	55.0	107.456	29.0
SH-35	0.84	70.3	- 4	0.3	1.0	1.67	34.5	107.456	18.2

AD-A031 902 AIR FORCE AERO PROPULSION LAB WRIGHT-PATTERSON AFB OHIO F/G 21/4
VISCOSITY MEASUREMENTS OF POTENTIAL HIGH DENSITY HYDROCARBON FU--ETC(U)
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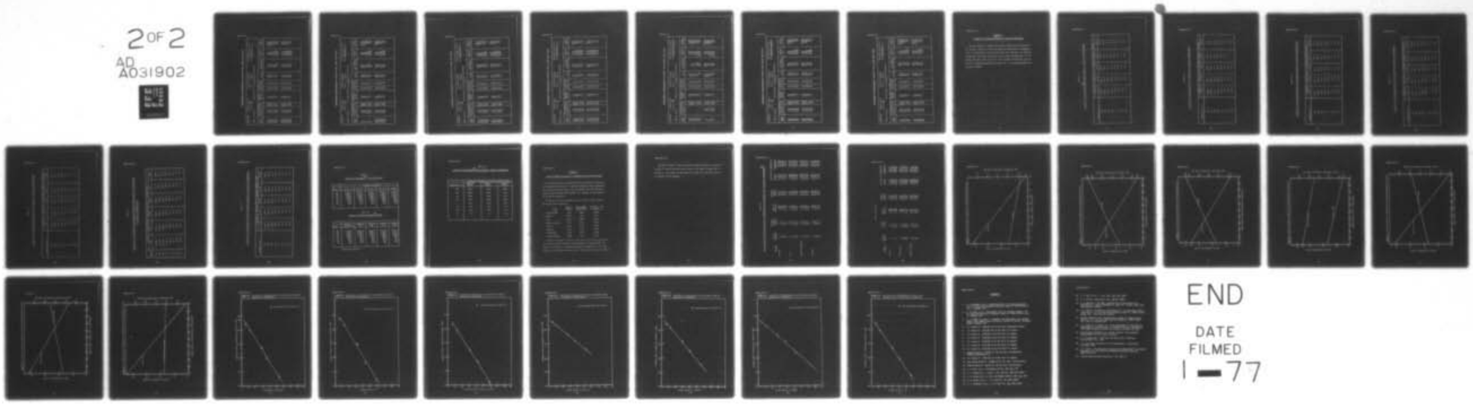

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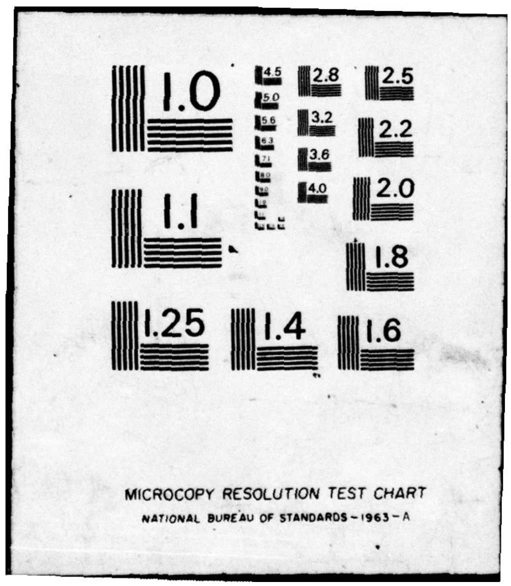
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm — Cone Angle 2° 0' 22" — Gap Setting 91 Microns

Flat Nr 865 — Cone Nr 1141 — RB # 55424 (14, 16)

TABLE D-2 (Cont'd) — Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-34	-1.93	-65.2	-123	0.3	3.0	167.0	217.5	1.075	11,448.4
SH-34	-1.65	-50.1	-110	0.3	3.0	167.0	67.8	1.075	3,568.7
SH-34	-1.47	-40.4	-102	0.3	3.0	167.0	34.0	1.075	1,789.6
SH-34	-1.18	-25.2	- 88	0.3	2.0	16.7	122.3	10.746	643.7
SH-34	-0.67	0	- 66	0.3	2.0	16.7	35.3	10.746	185.8
SH-34	-0.14	25.3	- 44	0.3	1.0	1.67	138.0	107.456	72.6
SH-34	0.40	50.3	- 22	0.3	1.0	1.67	70.0	107.456	36.8
SH-34	0.84	70.3	- 4	0.3	1.0	1.67	43.0	107.456	22.6
SH-38	-1.93	-65.2	-123	0.3	2.0	16.7	62.3	10.746	327.9
SH-38	-1.65	-50.1	-110	0.3	2.0	16.7	30.0	10.746	157.9
SH-38	-1.47	-40.4	-102	0.3	2.0	16.7	20.3	10.746	106.9
SH-38	-1.18	-25.2	- 88	0.3	1.0	1.67	115.5	107.456	60.8
SH-38	-0.67	0	- 66	0.3	1.0	1.67	50.0	107.456	26.3
SH-38	-0.14	25.3	- 44	0.3	1.0	1.67	29.5	107.456	15.5
SH-38	0.40	50.3	- 22	0.3	1.0	1.67	16.8	107.456	8.8
SH-38	0.84	70.3	- 4	0.3	1.0	1.67	11.5	107.456	6.1

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm   Cone Angle 2° 0' 22"   Gap Setting 91 Microns

Flat Nr 865   Cone Nr 1141   RB # 55418 (10 and 11)

TABLE D-2 (Cont'd)   Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH	-1.93	-65.2	-123	0.3	3.0	167.0	555.0	1.075	29,213.1
SH	-1.65	-50.1	-110	0.3	3.0	167.0	126.8	1.075	6,674.3
SH	-1.47	-40.4	-102	0.3	3.0	167.0	57.0	1.075	3,000.3
SH	-1.18	-25.2	- 88	0.3	3.0	167.0	22.0	1.075	1,158.0
SH	-0.67	0	- 66	0.3	2.0	16.7	53.3	10.746	280.6
SH	-0.14	25.3	- 44	0.3	2.0	16.7	20.0	10.746	105.3
SH	0.40	50.3	- 22	0.3	1.0	1.67	94.0	107.456	49.5
SH	0.84	70.3	- 4	0.3	1.0	1.67	56.0	107.456	29.5
SH-39	-1.93	-65.2	-123	0.3	3.0	167.0	171.0	1.075	9,000.8
SH-39	-1.65	-50.1	-110	0.3	3.0	167.0	48.8	1.075	2,568.7
SH-39	-1.47	-40.4	-102	0.3	3.0	167.0	25.8	1.075	1,358.0
SH-39	-1.18	-25.2	- 88	0.3	2.0	16.7	92.5	10.746	486.9
SH-39	-0.67	0	- 66	0.3	2.0	16.7	29.3	10.746	154.2
SH-39	-0.14	25.3	- 44	0.3	1.0	1.67	117.8	107.456	62.0
SH-39	0.40	50.3	- 22	0.3	1.0	1.67	60.0	107.456	31.6
SH-39	0.84	70.3	- 4	0.3	1.0	1.67	36.0	107.456	18.9

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22" Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55418 (12 and 13)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-40	-1.93	-65.2	-123	0.3	3.0	167.0	82.5	1.075	4,342.5
SH-40	-1.65	-50.1	-110	0.3	2.0	16.7	238.8	10.746	1,257.0
SH-40	-1.47	-40.4	-102	0.3	2.0	16.7	122.0	10.746	642.2
SH-40	-1.18	-25.2	- 88	0.3	2.0	16.7	52.5	10.746	276.3
SH-40	-0.67	0	- 66	0.3	2.0	16.7	17.4	10.746	91.6
SH-40	-0.14	25.3	- 44	0.3	1.0	1.67	74.5	10.746	39.2
SH-40	0.40	50.3	- 22	0.3	1.0	1.67	42.0	107.456	22.1
SH-40	.84	70.3	- 4	0.3	1.0	1.67	26.0	107.456	13.7
SH-41	-1.93	-65.2	-123	0.3	2.0	16.7	123.0	10.746	647.4
SH-41	-1.65	-50.1	-110	0.3	2.0	16.7	44.5	10.746	234.2
SH-41	-1.47	-40.4	-102	0.3	2.0	16.7	28.5	10.746	150.0
SH-41	-1.18	-25.2	- 88	0.3	1.0	1.67	143.0	107.456	75.3
SH-41	-0.67	0	- 66	0.3	1.0	1.67	61.3	107.456	32.3
SH-41	-0.14	25.3	- 44	0.3	1.0	1.67	31.0	107.456	16.3
SH-41	0.40	50.3	- 22	0.3	1.0	1.67	19.0	107.456	10.0
SH-41	0.84	70.3	- 4	0.3	1.0	1.67	13.5	107.456	7.1

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22'' Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55418 (14 and 15)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-42	-1.93	-65.2	-123	0.3	2.0	16.7	56.0	10.746	294.7
SH-42	-1.65	-50.1	-110	0.3	2.0	16.7	24.5	10.746	129.0
SH-42	-1.47	-40.4	-102	0.3	1.0	1.67	157.5	107.456	82.9
SH-42	-1.18	-25.2	- 88	0.3	1.0	1.67	80.0	107.456	42.0
SH-42	-0.67	0	- 66	0.3	1.0	1.67	39.0	107.456	20.5
SH-42	-0.14	25.3	- 44	0.3	1.0	1.67	20.0	107.456	10.5
SH-42	0.40	50.3	- 22	0.3	1.0	1.67	12.0	107.456	6.3
SH-42	0.84	70.3	- 4	0.3	1.0	1.67	9.5	107.456	5.0
SH-43	-2.20	-80.0	-123	0.3	2.0	16.7	41.5	10.746	218.4
SH-43	-1.93	-65.2	-123	0.3	1.0	1.67	200.0	107.456	105.2
SH-43	-1.65	-50.1	-110	0.3	1.0	1.67	87.0	107.456	45.8
SH-43	-1.47	-40.4	-102	0.3	1.0	1.67	64.0	107.456	33.7
SH-43	-1.18	-25.2	- 88	0.3	1.0	1.67	37.0	107.456	19.5
SH-43	-0.67	0	- 66	0.3	1.0	1.67	18.5	107.456	9.7
SH-43	-0.14	25.3	- 44	0.3	1.0	1.67	10.8	107.456	5.7
SH-43	0.40	50.3	- 22	0.3	1.0	1.67	7.5	107.456	3.9
SH-43	0.84	70.3	- 4	0.3	1.0	1.67	6.0	107.456	3.2

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm   Cone Angle 2° 0' 22"   Gap Setting 91 Microns

Flat Nr 865   Cone Nr 1141   RB # 55422 (4) and 55418 (17)

TABLE D-2 (Cont'd)   Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SH-E		-65.2	-123	0.3	3.0	167.0		1.075	frozen
SH-E		-50.0	-110	0.3	3.0	167.0		1.075	frozen
SH-E		-40.0	-102	0.3	3.0	167.0	335.0	1.075	17,633.2
SH-E		-25.0	- 88	0.3	3.0	167.0	21.0	1.075	1,105.4
SH-E		0	- 66	0.3	3.0	167.0	5.1	1.075	268.4
SH-E		0	- 66	0.3	2.0	16.7	50.5	10.746	268.8
SH-E		25.0	- 44	0.3	2.0	16.7	19.63	10.746	103.3
SH-E		50.0	- 22	0.3	1.0	1.67	87.5	107.456	46.1
SH-E		70.0	- 4	0.3	1.0	1.67	54.0	107.456	28.4
SH	-1.93	-65.2	-123	0.3	3.0	167.0	650.0	1.075	34,213.6
SH	-1.65	-50.1	-110	0.3	3.0	167.0	139.5	1.075	7,342.8
SH	-1.47	-40.4	-102	0.3	3.0	167.0	58.5	1.075	3,079.2
SH	-1.18	-25.2	- 88	0.3	3.0	167.0	20.5	1.075	1,079.0
SH	-0.67	0	- 66	0.3	2.0	16.7	56.0	10.746	294.8
SH	-0.14	25.3	- 44	0.3	2.0	16.7	19.0	10.746	100.0
SH	0.40	50.3	- 22	0.3	1.0	1.67	94.0	107.456	49.5
SH	0.84	70.3	- 4	0.3	1.0	1.67	55.0	107.456	28.9

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22" Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55424 (29) and 55418 (2)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SHA	-1.93	-65.2	-123	0.3	3.0	167.0	670.0	1.075	35,266.4
SHA	-1.65	-50.1	-110	0.3	3.0	167.0	130.0	1.075	6,842.7
SHA	-1.47	-40.4	-102	0.3	3.0	167.0	66.5	1.075	3,500.3
SHA	-1.18	-25.2	- 88	0.3	3.0	167.0	21.8	1.075	1,147.5
SHA	-0.67	0	- 66	0.3	2.0	16.7	55.0	10.746	289.5
SHA	-0.14	25.3	- 44	0.3	2.0	16.7	21.0	10.746	110.5
SHA	0.40	50.3	- 22	0.3	1.0	1.67	95.0	107.456	50.0
SHA	0.84	70.3	- 4	0.3	1.0	1.67	52.5	107.456	27.6
SHB	-1.93	-65.2	-123	0.3	3.0	167.0	503.0	1.075	26,476.0
SHB	-1.65	-50.1	-110	0.3	3.0	167.0	132.5	1.075	6,974.3
SHB	-1.47	-40.4	-102	0.3	3.0	167.0	58.0	1.075	3,052.9
SHB	-1.18	-25.2	- 88	0.3	3.0	167.0	20.0	1.075	1,052.7
SHB	-0.67	0	- 66	0.3	2.0	16.7	52.8	10.746	277.9
SHB	-0.14	25.3	- 44	0.3	2.0	16.7	18.3	10.746	96.3
SHB	0.40	50.3	- 22	0.3	1.0	1.67	87.8	107.456	46.2
SHB	0.84	70.3	- 4	0.3	1.0	1.67	50.0	107.456	26.3

WEISSENBERG RHEOGONIOMETER VISCOSITY DATA (CONE AND PLATE)

PLATEN DATA: Diameter 5.0 cm Cone Angle 2° 0' 22" Gap Setting 91 Microns

Flat Nr 865 Cone Nr 1141 RB # 55418 (3 and 8)

TABLE D-2 (Cont'd) Torsion Bar Data: K_T = 1.851 X 10' Dyne-cm/Micron

Sample Number	Test Temperatures		Gap Setting Adjustment Microns	Transmission		t Sec/Rev	Δm, Microns (Meter Reading)	σ Shear Rate Sec^{-1}	μ Viscosity Centipoise
	Millivolts	°F		Left	Right				
SHC	-1.93	-65.2	-123	0.3	3.0	167.0	498.0	1.075	26,212.9
SHC	-1.65	-50.1	-110	0.3	3.0	167.0	127.8	1.075	6,726.9
SHC	-1.47	-40.4	-102	0.3	3.0	167.0	55.0	1.075	2,895.0
SHC	-1.18	-25.2	- 88	0.3	3.0	167.0	19.5	1.075	1,026.4
SHC	-0.67	0	- 66	0.3	2.0	16.7	50.5	10.746	265.8
SHC	-0.14	25.3	- 44	0.3	2.0	16.7	19.3	10.746	101.6
SHC	0.40	50.3	- 22	0.3	1.0	1.67	87.5	107.456	46.1
SHC	0.84	70.3	- 4	0.3	1.0	1.67	50.0	107.456	26.3
SHD	-1.93	-65.2	-123	0.3	3.0	167.0	750.0	1.075	39,477.3
SHD	-1.65	-50.1	-110	0.3	3.0	167.0	154.5	1.075	8,132.3
SHD	-1.47	-40.4	-102	0.3	3.0	167.0	74.5	1.075	3,921.4
SHD	-1.18	-25.2	- 88	0.3	3.0	167.0	24.8	1.075	1,305.4
SHD	-0.67	0	- 66	0.3	2.0	16.7	60.5	10.746	318.5
SHD	-0.14	25.3	- 44	0.3	2.0	16.7	21.3	10.746	112.1
SHD	0.40	50.3	- 22	0.3	1.0	1.67	100.0	107.456	52.6
SHD	0.84	70.3	- 4	0.3	1.0	1.67	55.0	107.456	29.0

APPENDIX E

VISCOSITY OF SHELLDYNE-H® BLENDS AT VARIOUS TEMPERATURES

The data tabulated in Appendix D have been reduced and are tabulated in this section. Since all of the test blends were determined to be Newtonian, there is no variation of viscosity with shear rate; therefore, no reference is made here to the shear rates used in the various determinations. For all testing, the shear rates were either 1.074, 10.746 or 107.456 sec^{-1} and can be found in the data presentation in Table D-2. The volume percentages were calculated at 60°F.

TABLE E-1

VISCOSITY OF SHELLDYNE-H®/TOLUENE BLENDS AT VARIOUS TEMPERATURES

Temperature, °F	VISCOSITY, CENTIPOISE AT VARIOUS VOLUME % TOLUENE				
	5.1%	12.3%	29.1%	35.1%	53.7%
-65	4,489.9	1947.5	289.5	110.5	27.8
-50	1,500.1	664.8	138.4	57.9	18.8
-40	842.2	381.6	92.1	40.0	13.7
-25	342.1	189.5	54.0	25.0	9.7
0	115.8	70.4	24.5	13.7	5.7
25	51.3	34.2	15.8	10.0	3.9
50	25.3	19.7	10.4	7.4	3.0
70	17.9	13.9	8.7	6.8	2.6

TABLE E-2

VISCOSITY OF SHELLDYNE-H/JP-4 BLENDS AT VARIOUS TEMPERATURES

Temperature, °F	VISCOSITY, CENTIPOISE AT VARIOUS VOLUME % TOLUENE				
	6.9%	13.5%	31.9%	42.1%	58.4%
-65	7,658.6	2763.4	336.9	157.9	55.3
-50	2,184.4	888.5	145.4	81.0	31.8
-40	1,131.7	539.5	97.4	56.6	23.2
-25	447.4	244.8	56.6	34.2	15.3
0	147.4	86.9	26.3	17.4	9.0
25	61.8	39.0	16.5	10.7	6.7
50	30.0	21.3	10.5	7.1	4.9
70	20.0	14.4	8.2		3.9

TABLE E-3

VISCOSITY OF SHELLDYNE-H/METHYLCYCLOHEXANE BLENDS AT VARIOUS TEMPERATURES

Temperature, °F	VISCOSITY, CENTIPOISE, AT VARIOUS VOLUME % MCH				
	6.9%	13.5%	31.9%	43.1%	58.4%
-65	6,043.1	2,237.0	321.1	167.4	42.1
-50	1,805.4	835.9	154.2	88.2	26.3
-40	968.5	479.0	104.6	63.2	20.7
-25	407.9	227.9	59.2	39.5	14.7
0	134.2	82.9	29.7	22.6	8.2
25	57.9	39.5	21.1	14.7	4.5
50	29.0	21.8	13.2	9.7	3.4
70	19.5	15.3	10.5	7.9	3.0

TABLE E-4

VISCOSITY OF SHELLDYNE-H/TETRALIN BLENDS AT VARIOUS TEMPERATURES

Temperature, °F	VISCOSITY, CENTIPOISE, AT VARIOUS VOLUME % TETRALIN				
	5.5%	10.9%	26.8%	37.1%	52.3%
-65	13,159.1	7,974.4	1,710.7	974.5	394.8
-50	3,921.4	2,158.1	664.8	342.1	157.9
-40	1,631.7	1,042.2	329.0	213.2	92.1
-25	658.0	426.4	152.6	101.6	47.6
0	189.5	133.2	58.6	34.7	21.1
25	71.1	55.3	25.3	17.9	11.8
50	32.9	26.3	14.2	11.1	7.1
70	20.5	16.8	9.7	7.3	4.9

TABLE E-5

VISCOSITY OF SHELLDYNE-H/TRANS-DECALIN BLENDS AT VARIOUS TEMPERATURES

Temperature, °F	VISCOSITY, CENTIPOISE AT VARIOUS VOLUME % T-DECALIN				
	5.9%	11.9%	29.0%	39.7%	54.8%
-65	11,448.4	6,105.8	1,210.6	509.5	189.5
-50	3,568.7	2,000.2	454.3	207.9	94.7
-40	1,789.6	1,015.9	276.3	139.5	62.5
-25	643.7	421.1	146.3	79.0	38.3
0	185.8	143.7	53.7	33.7	19.2
25	72.6	57.9	26.3	18.8	11.6
50	26.8	29.0	15.2	10.8	7.4
70	22.6	18.2	11.1	7.6	5.5

TABLE E-6

VISCOSITY OF SHELLDYNE-H/TETRAHYDRO-METHYLCYCLOPENTADIENE DIMER BLENDS AT VARIOUS TEMPERATURES

Temp., °F	VISCOSITY, CENTIPOISE AT VARIOUS VOLUME % TH-MCPD DIMER					
	5.7%	11.5%	27.8%	38.3%	53.7	100%
-65	18,686.0	14,211.9	4,684.7	2,895.0	1,410.7	493.7
-50	4,474.1	2,974.0	1,500.1	894.8	493.7	121.1
-40	2,158.1	1,658.1	936.9	500.0	289.5	76.3
-25	947.5	710.6	357.9	254.3	149.9	43.4
0	234.2	168.4	125.3	88.4	60.5	21.5
25	94.7	68.4	52.6	40.5	29.2	12.3
50	39.6	34.2	24.2	20.3	15.9	7.4
70	23.9	20.5	15.8	13.4	11.1	5.3

TABLE E-7

VISCOSITY OF SHELLDYNE-H/ISOBUTYLBENZENE BLENDS AT VARIOUS TEMPERATURES

Temperature, °F	VISCOSITY, CENTIPOISE AT VARIOUS VOLUME % IBB				
	6.2%	12.3%	29.6%	40.3%	55.8%
-65	9,000.8	4,342.5	647.4	294.7	105.2
-50	2,568.7	1,257.0	234.2	129.0	45.8
-40	1,358.0	642.2	150.0	82.9	33.7
-25	486.9	276.3	75.3	42.0	19.5
0	154.2	91.6	32.3	20.5	9.7
25	62.0	39.2	16.3	10.5	5.7
50	31.6	22.1	10.0	6.3	3.9
70	18.9	13.7	7.1	5.0	3.2

TABLE E-8

VISCOSITY OF SHELLDYNE-H® - LOT #LR-11410-103

Temp., °F	Viscosity, Centipoise				
	Run Nr 1	Run Nr 2	Run Nr 3	Run Nr 4	Average
-65	31,581.8	30,818.6	29,213.1	34,213.6	31,456.8
-50	7,369.1	7,174.3	5,674.3	7,342.8	7,140.1
-40	3,184.5	3,105.5	3,000.3	3,079.2	3,092.4
-25	1,094.8	1,094.8	1,158.0	1,079.0	1,106.7
0	283.2	276.3	280.6	294.8	283.7
25	99.0	102.6	105.3	100.0	101.7
50	47.9	47.9	49.5	49.5	48.7
70	26.8	27.4	29.5	28.9	28.2

TABLE E-9

VISCOSITY OF VARIOUS SHELLDYNE-H® BATCHES

Temp., °F	*Batch Nr LR-11410-103	Sample Nr SHA	Sample Nr SHB	Sample Nr SHC	Sample Nr SHD
-65	31,456.8	35,266.4	26,476.0	26,212.9	39,477.3
-50	7,140.1	6,842.7	6,974.3	6,726.9	8,132.3
-40	3,092.4	3,500.3	3,052.9	2,895.0	3,921.4
-25	1,106.7	1,147.5	1,052.7	1,026.4	1,305.4
0	283.7	289.5	277.9	265.8	318.5
25	101.7	110.5	96.3	101.6	112.1
50	48.7	50.0	46.2	46.1	52.6
70	28.2	27.6	26.3	26.3	29.0

* Average from Table E-8

TABLE E-10

VISCOSITY OF SHELLDYNE-H®/DECALIN BLENDS AT VARIOUS TEMPERATURES

	Viscosity, Centipoise, of various Decalin Blends		
Temperature, °F	Sample Nr SH-22A	Sample Nr SH-38	Sample Nr SH-26A
-65	452.7	327.9	189.5
-50	209.5	157.9	94.7
-40	138.4	106.9	62.5
-25	76.3	60.8	38.3
0	34.2	26.3	19.2
25	17.9	15.5	11.6
50	10.9	8.8	7.4
70	7.4	6.1	5.5

APPENDIX F

CALCULATED DENSITIES AND HEATS OF COMBUSTION FOR THE VARIOUS BLENDS

This section contains the calculated densities and heats of combustion for the various test mixtures. It has been assumed that these hydrocarbons form ideal solutions when mixed. The pure component densities and heats of combustion were extracted from handbooks, when available, or were measured in the petroleum laboratory.

Following are the pure component values for specific gravity, density and the net heat of combustion.

Fluid	Specific Gravity	Density @60°F Pounds/Gallon	Net Heat of Comb. Btu/Lb
Shelldyne-H®	1.065	8.859	17,890
Toluene	0.873	7.262	17,412
JP-4	0.755	6.280	18,840
Methylcyclohexane	0.776	6.455	18,790
Tetralin	0.975	8.110	17,390
t-Decalin	0.870	7.236	18,340
TH-MCPD Dimer	0.925	7.694	17,925
Iso-Butylbenzene	0.860	7.155	17,834

Figures F-1 through F-7 are plots of the densities and heats of combustion for the various binary mixtures of the hydrocarbons in Shelldyne-H®. From Figures F-1 through F-7, the densities and heats of combustion for the blends evaluated in this program were determined. These data are presented in Table F-1.

The data in Table F-1 were then used to obtain the plots in Figures F-8 through F-14 where the calculated volumetric net heats of combustion are plotted vs. the volumetric percentage of diluents for the binary mixtures of interest in this program.

TABLE F-1

THE CALCULATED DENSITIES AND HEATS OF COMBUSTION OF THE VARIOUS TEST DILUENTS IN SHELLDYNE-H®

Diluent	Diluent Weight %	Diluent Volume % (60°F)	Specific Gravity	Density Lbs/Gal (60°F)	NET HEAT OF COMBUSTION Btu/lb	Btu/Gallon
Toluene	5	5.1	1.058	8.814	17,870	157,509
	10	12.3	1.048	8.731	17,841	155,768
	25	29.1	1.018	8.481	17,770	150,707
	35	35.1	0.998	8.341	17,721	147,818
	50	53.7	0.970	8.081	17,650	142,631
JP-4	5	6.9	1.051	8.756	17,938	157,063
	10	13.5	1.036	8.631	17,988	155,253
	25	31.9	0.989	8.239	18,138	149,445
	35	43.1	0.951	7,922	18,238	144,496
	50	58.4	0.911	7,590	18,385	139,534
Methylcyclohexane	5	6.9	1.052	8.764	17,930	157,142
	10	13.5	1.037	8.639	17,978	155,316
	25	31.9	0.993	8.273	18,106	149,785
	35	43.0	0.965	8.039	18,200	146.317
	50	58.3	0.921	7.673	18,340	140,721
Tetralin	5	5.5	1.063	8.856	17,864	158,201
	10	10.9	1.058	8.814	17,839	157,236
	25	26.8	1.044	8.698	17,764	154,504
	35	37.1	1.035	8.623	17,715	152,749
	50	52.3	1.022	8.514	17,640	150,192

TABLE F-1 (Cont'd)

Diluent	Diluent Weight %	Diluent Volume % (60°F)	Specific Gravity	Density Lbs/Gal (60°F)	NET HEAT OF COMBUSTION Btu/lb	NET HEAT OF COMBUSTION Btu/Gallon
t-Decalin	5	5.9	1.058	8.814	17,911	157,063
	10	11.9	1.048	8.731	17,933	156,571
	25	29.0	1.018	8.481	18,002	152,674
	35	39.7	0.997	8.306	18,047	149,899
	50	54.8	0.968	8.064	18,115	146,087
TH-MCPD Dimer	5	5.7	1.060	8.831	17,906	158,125
	10	11.5	1.052	8.764	17,922	157,072
	25	27.8	1.031	8.589	17,973	154,374
	35	38.3	1.016	8.464	18,006	152,408
	50	53.9	0.994	8.281	18,056	149,522
Isobutyl-Benzene	5	6.2	1.057	8.805	17,887	157,511
	10	12.3	1.045	8.706	17,884	155,696
	25	29.6	1.012	8.431	17,876	150,712
	35	40.3	0.992	8.264	17,870	147,684
	50	55.8	0.961	8.006	17,862	143,005

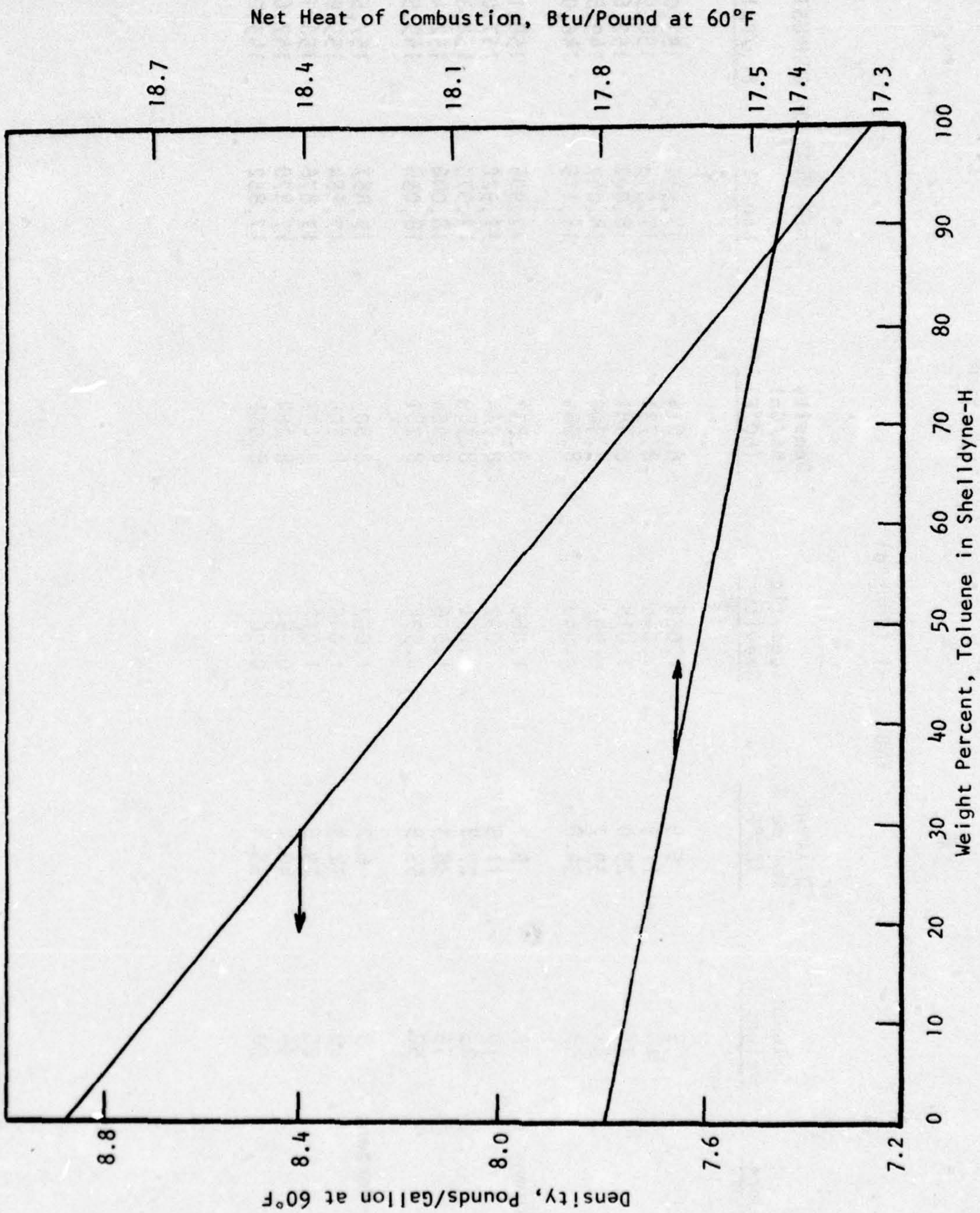
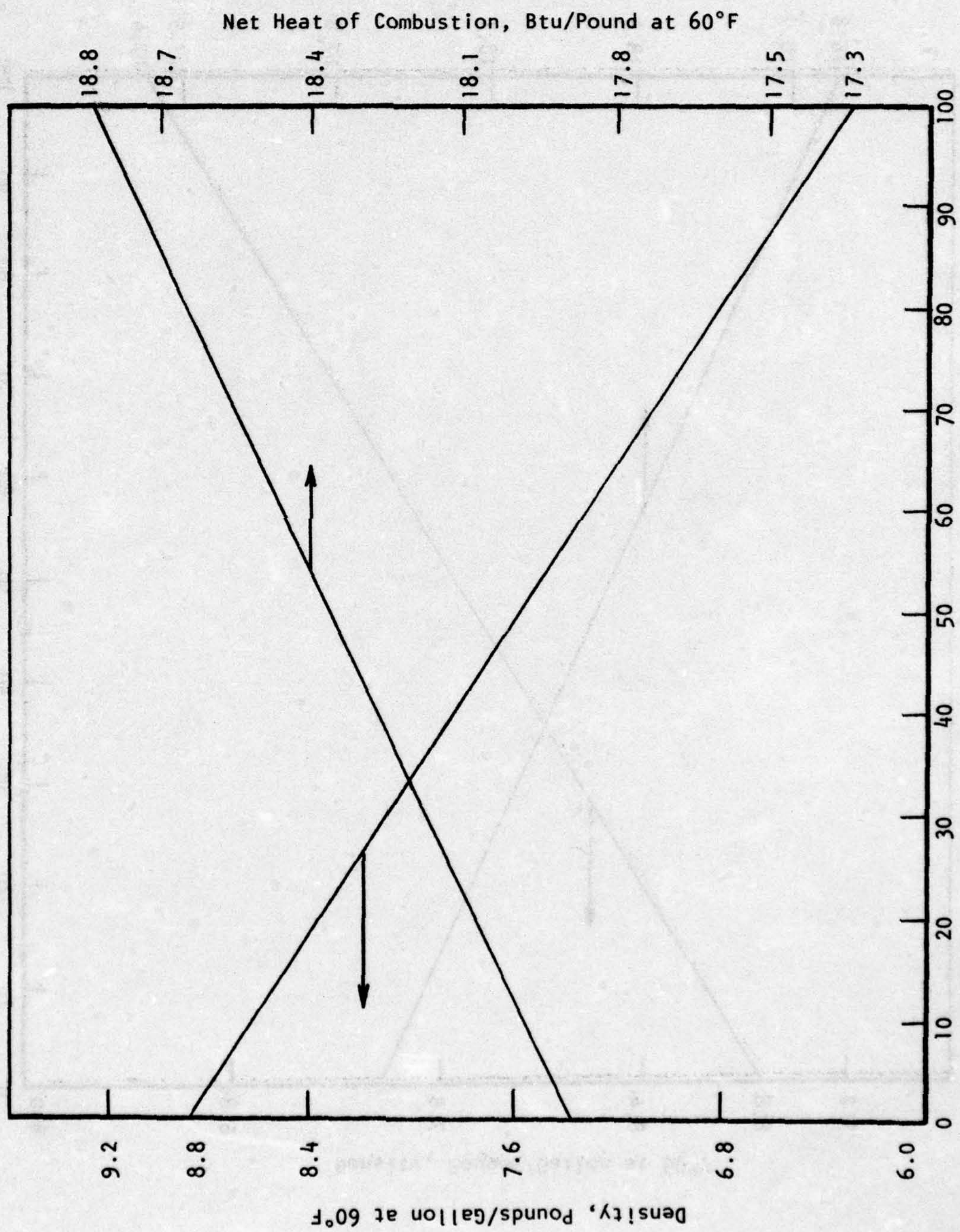


FIGURE F-1. Density and Heats of Combustion of Shelldyne-H/Toluene Mixtures

FIGURE F-2. Density and Heat of Combustion of Shelldyne-H/JP-4 Mixtures



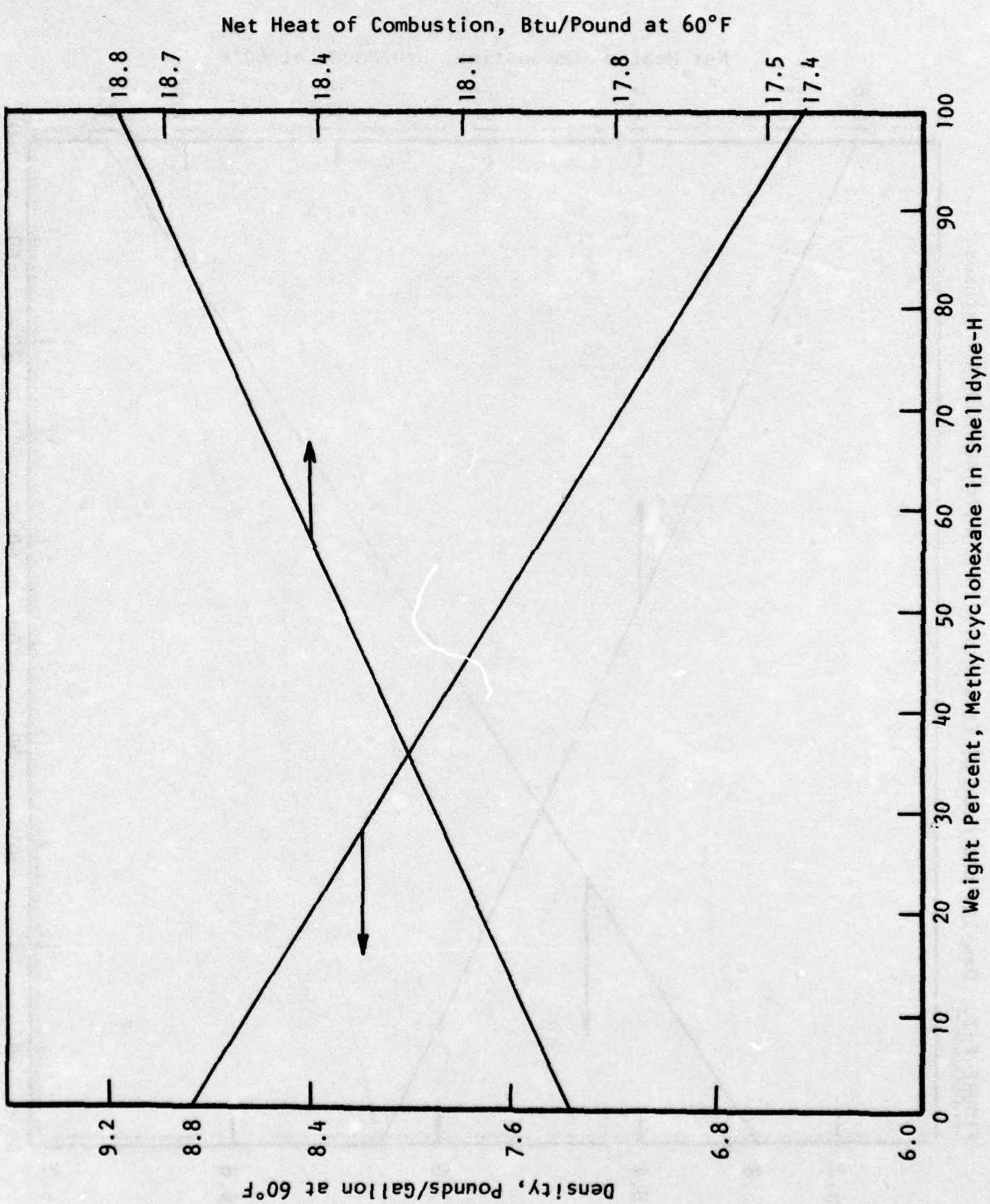


FIGURE F-3. Density and Heat of Combustion of Shelldyne-H/MCH Mixtures

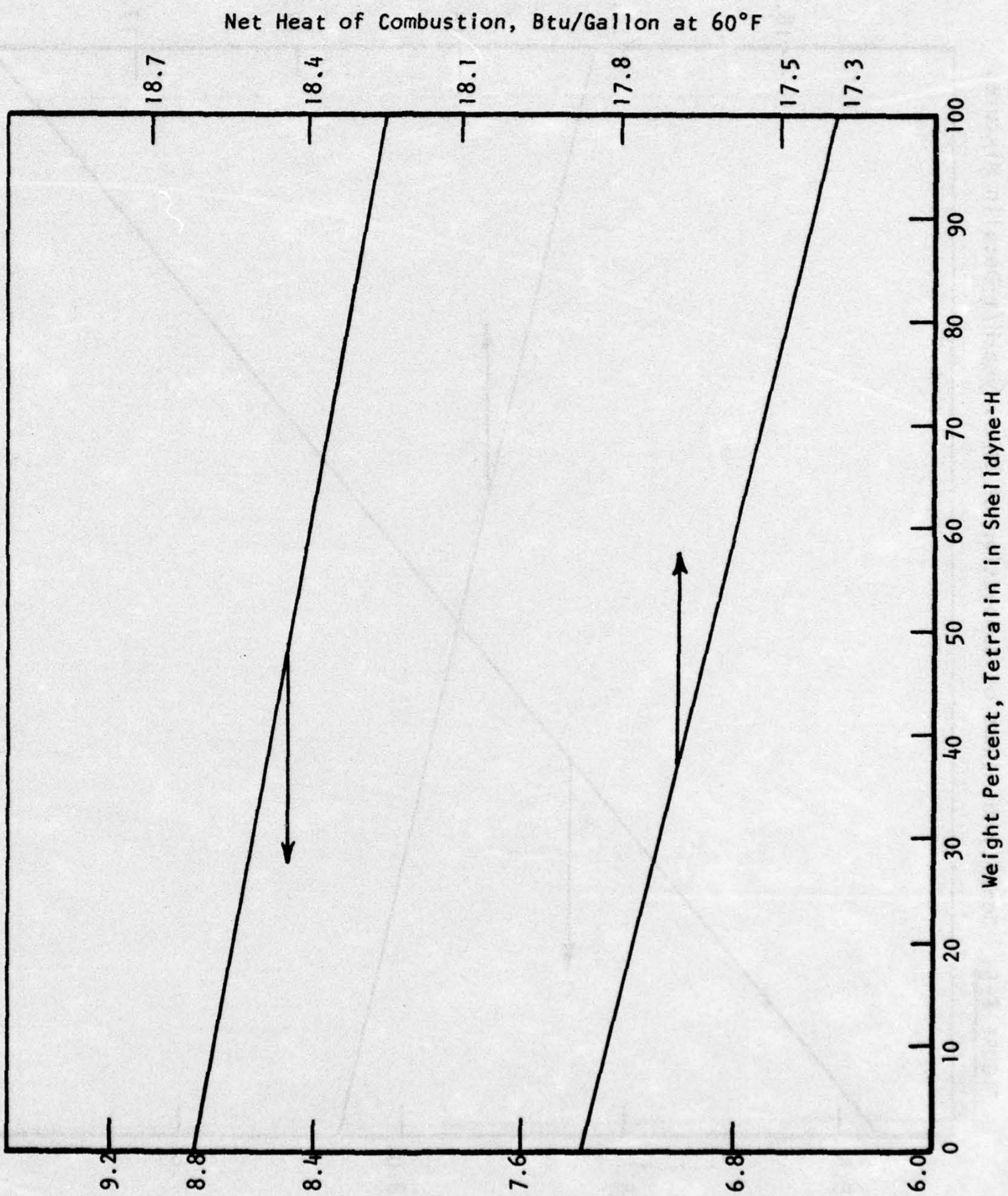


FIGURE F-4. Density and Heat of Combustion of Shelldyne-H/Tetralin Mixtures

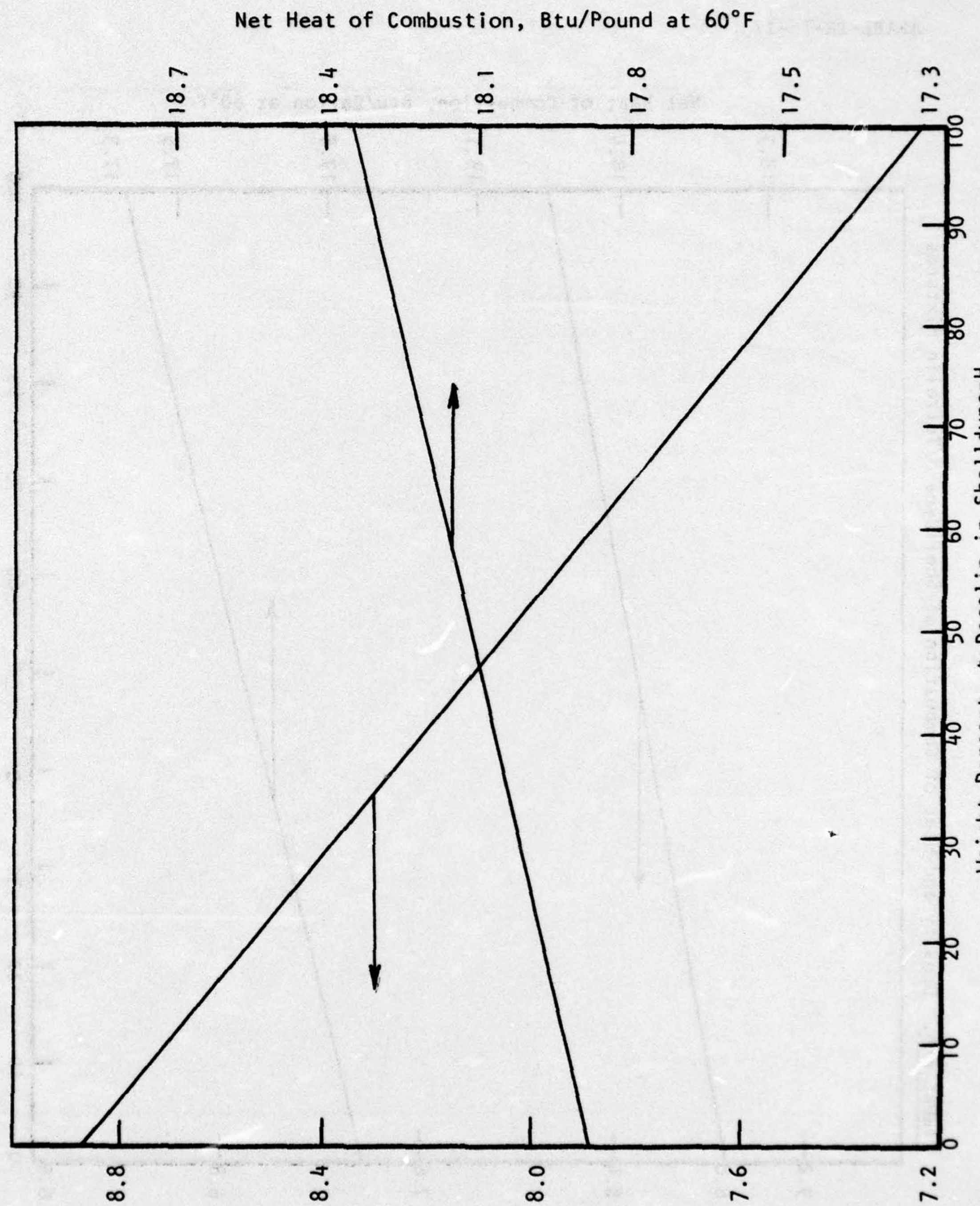


FIGURE F-5. Density and Heat of Combustion of Shelldyne-H/t-Decalin Mixtures

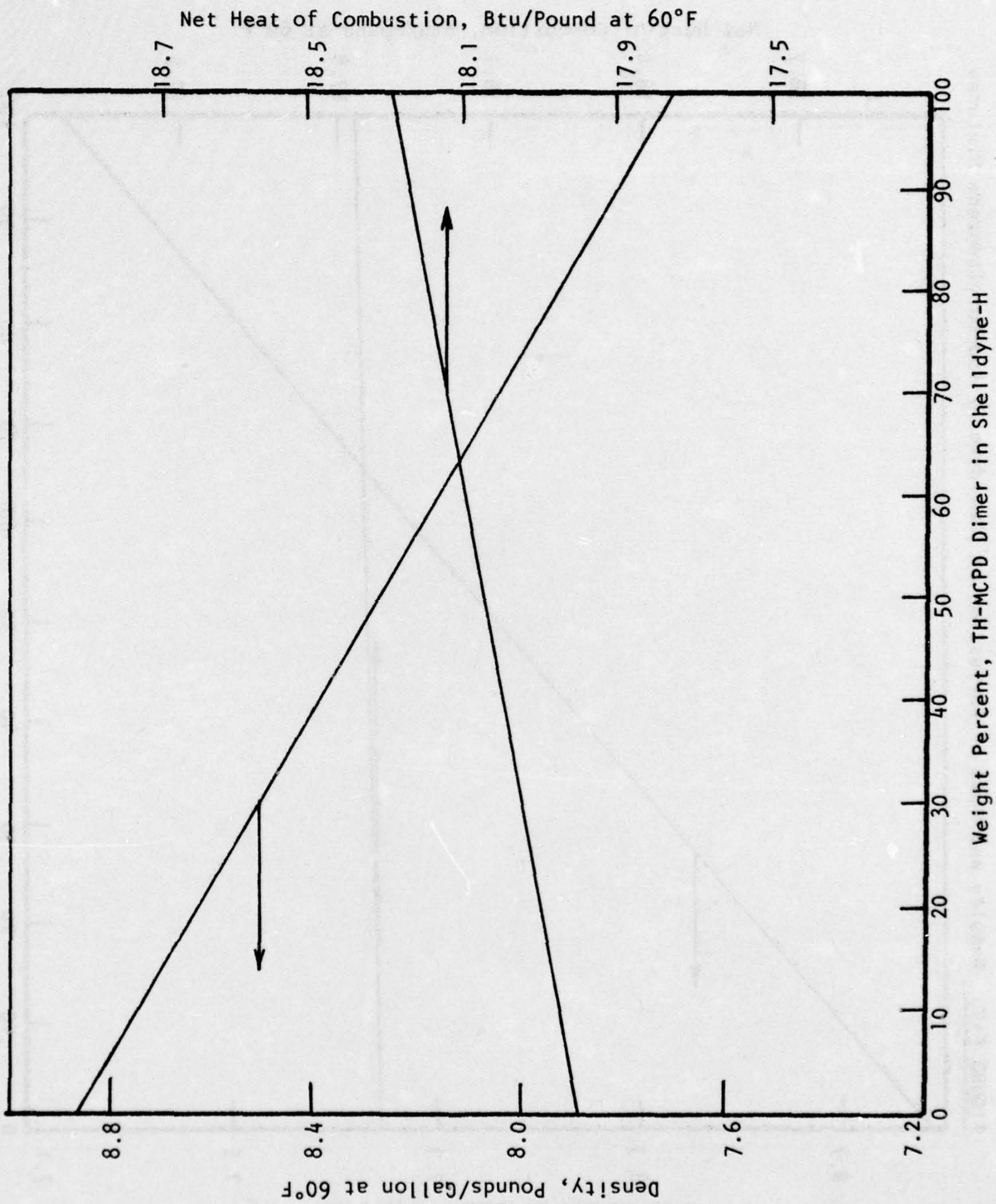


FIGURE F-6. Density and Heat of Combustion of Shelldyne-H/TH-MCPD Dimer Mixture

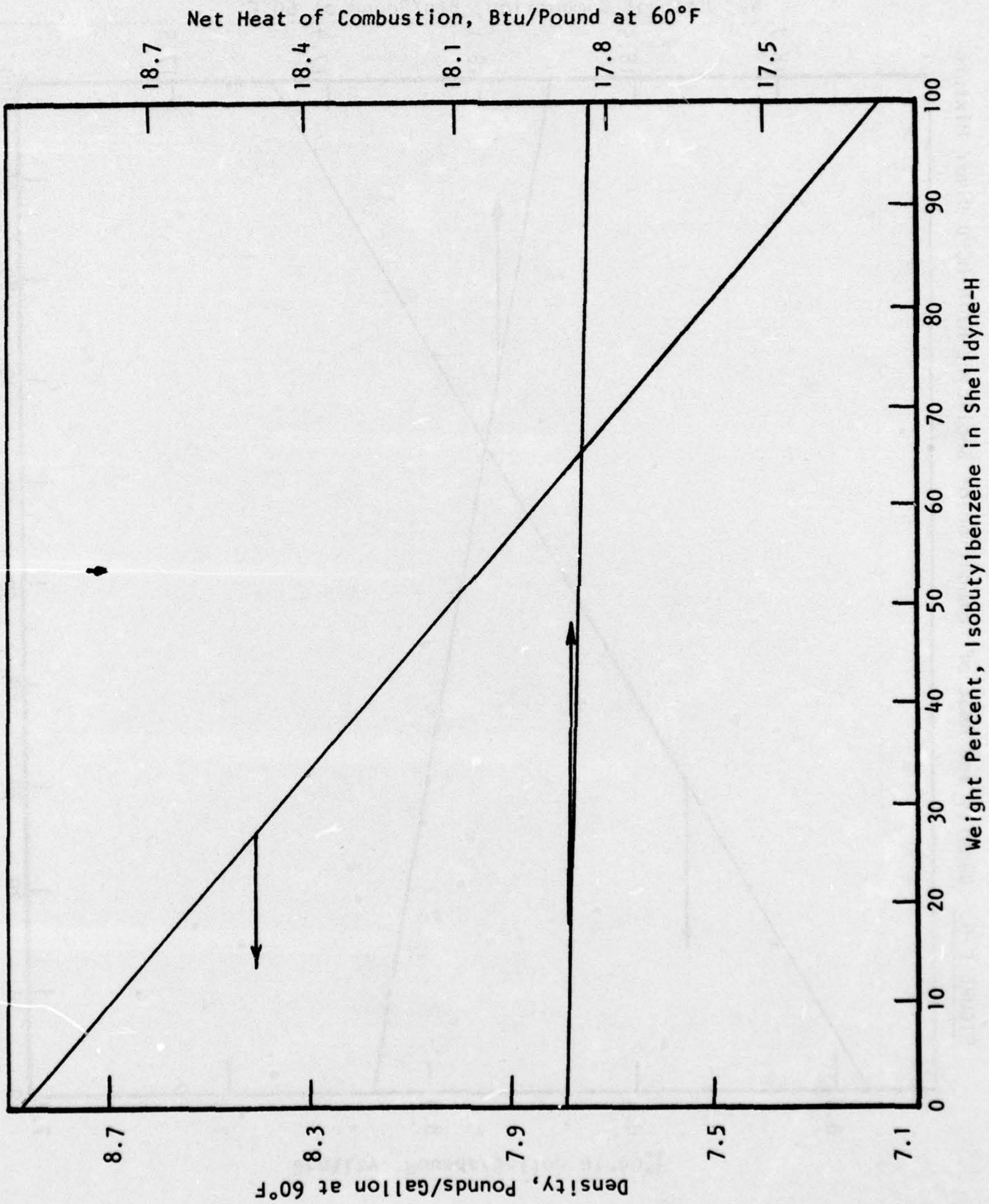


FIGURE F-7. Density and Heat of Combustion of Shelldyne-H/ Iso-butylbenzene Mixtures

FIGURE F-8. The Effect of Toluene Dilution on the Volumetric Heat of Combustion of Shelldyne-H.

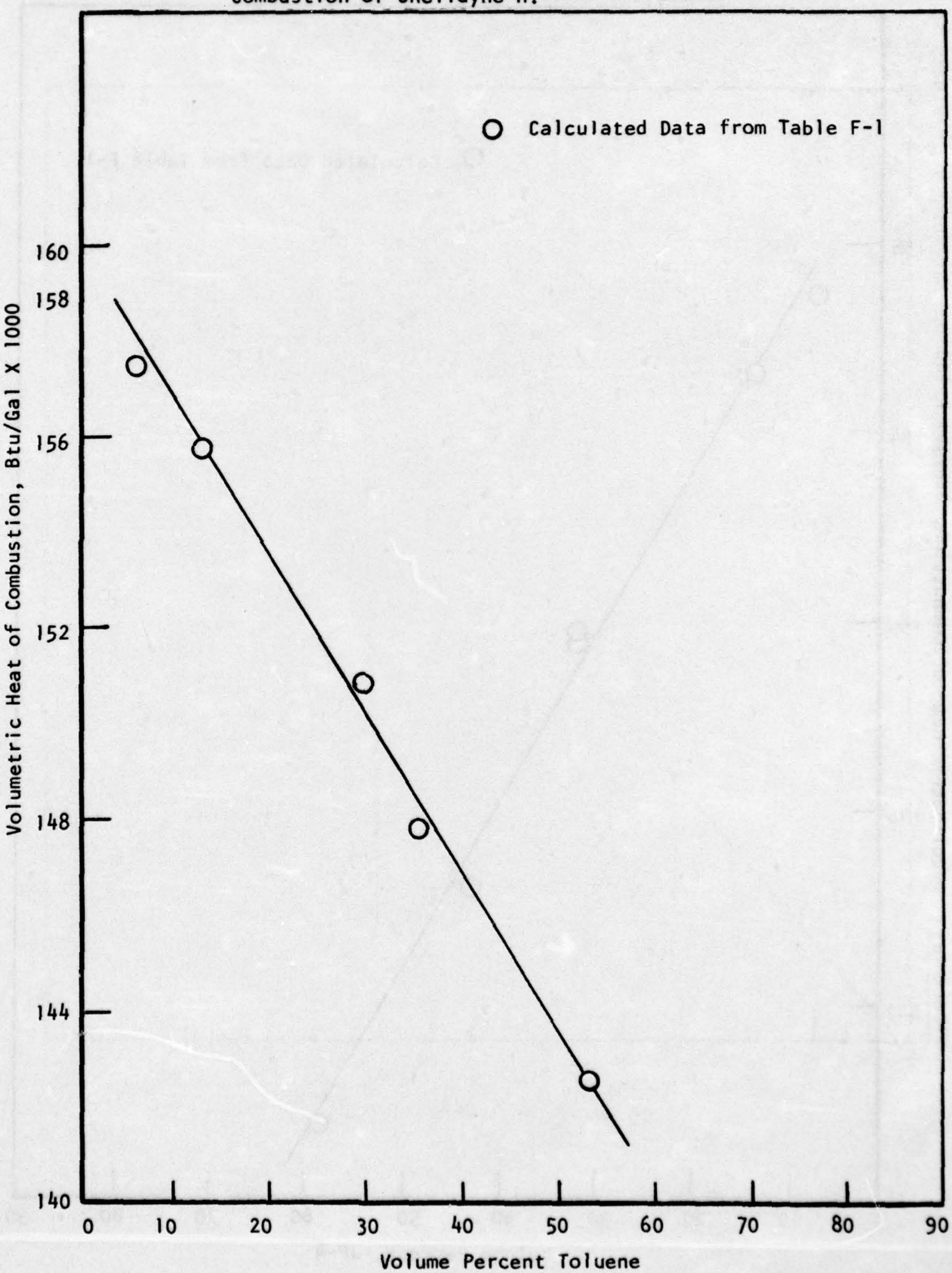


FIGURE F-9. The Effect of JP-4 Dilution on the Volumetric Heat of Combustion of Shelldyne-H.

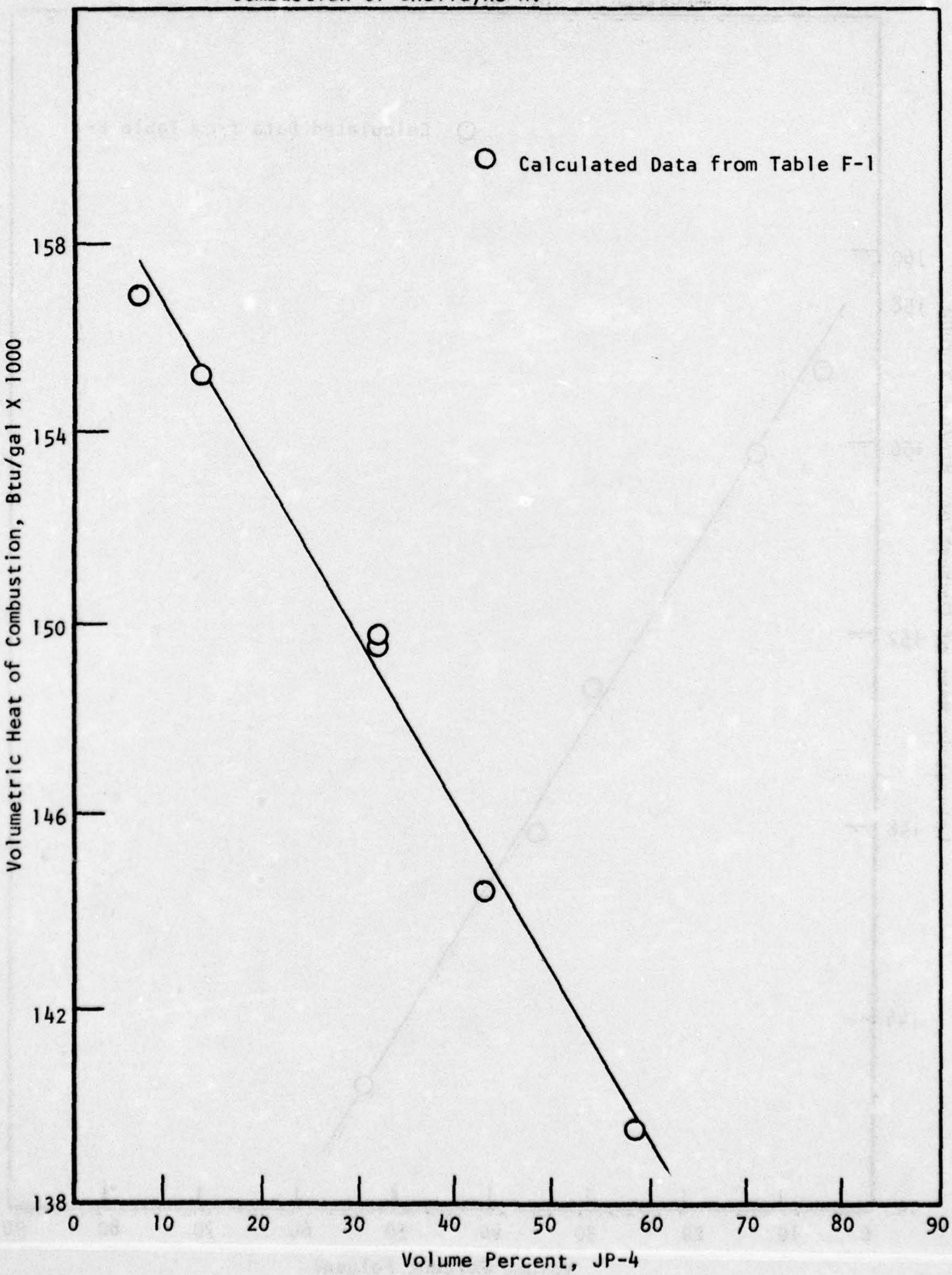


FIGURE F-10. The Effect of MCH Dilution on the Volumetric Heat of Combustion of Shelldyne-H.

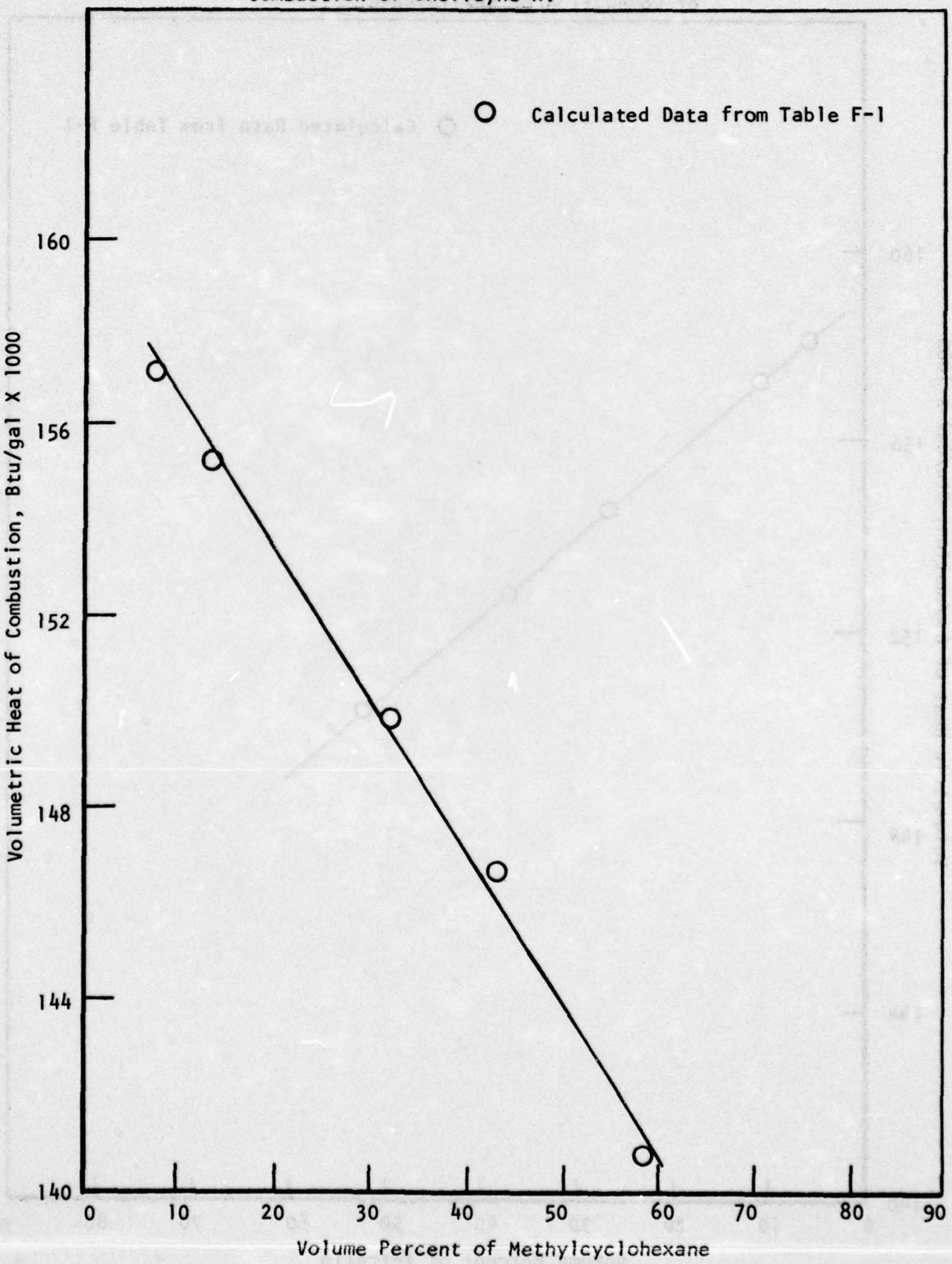


Figure F-11. The Effect of Tetralin Dilution on the Volumetric Heat of Combustion of Shelldyne-H.

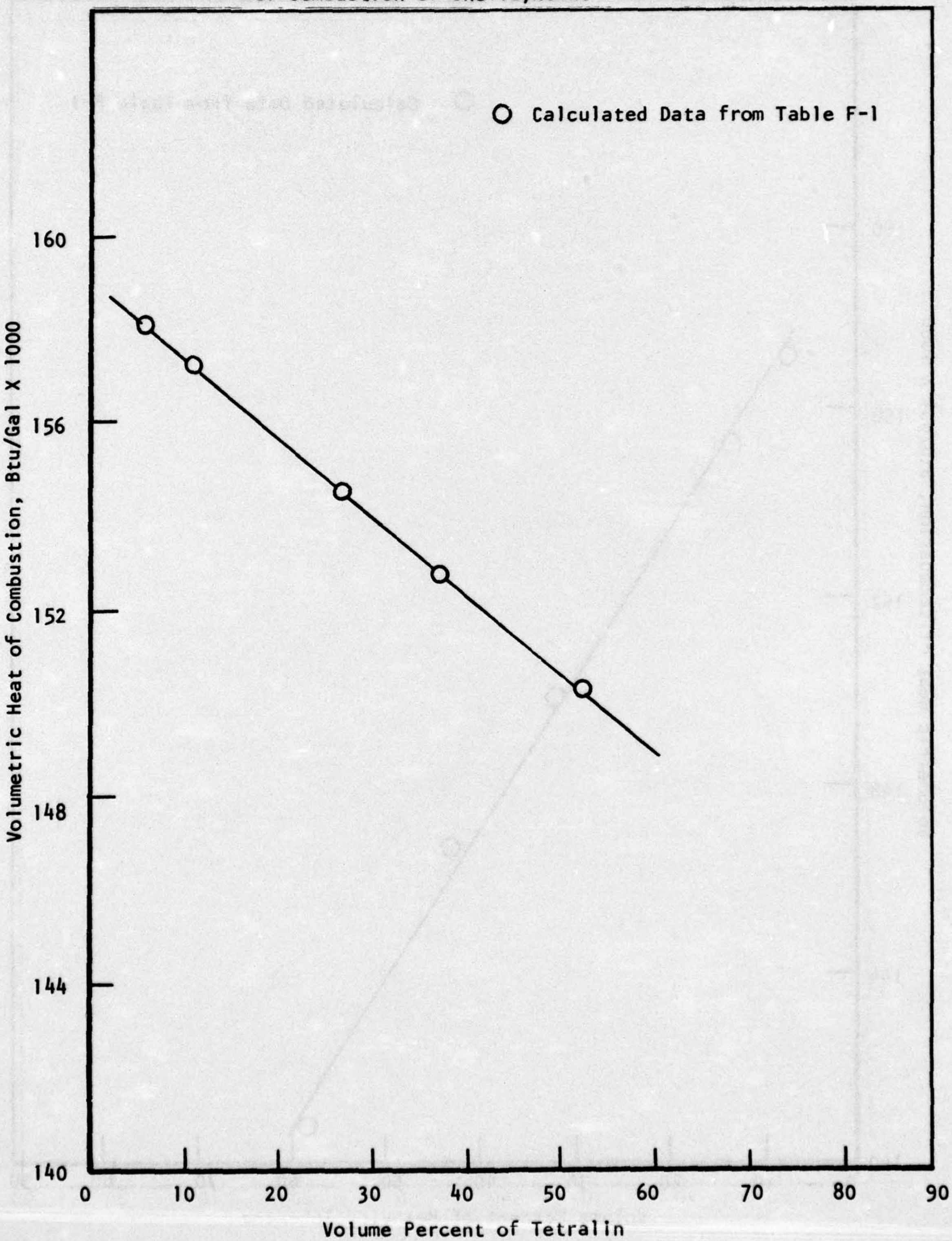


FIGURE F-12. The Effect of Trans Decalin on the Volumetric Heat of Combustion of Shelldyne-H.

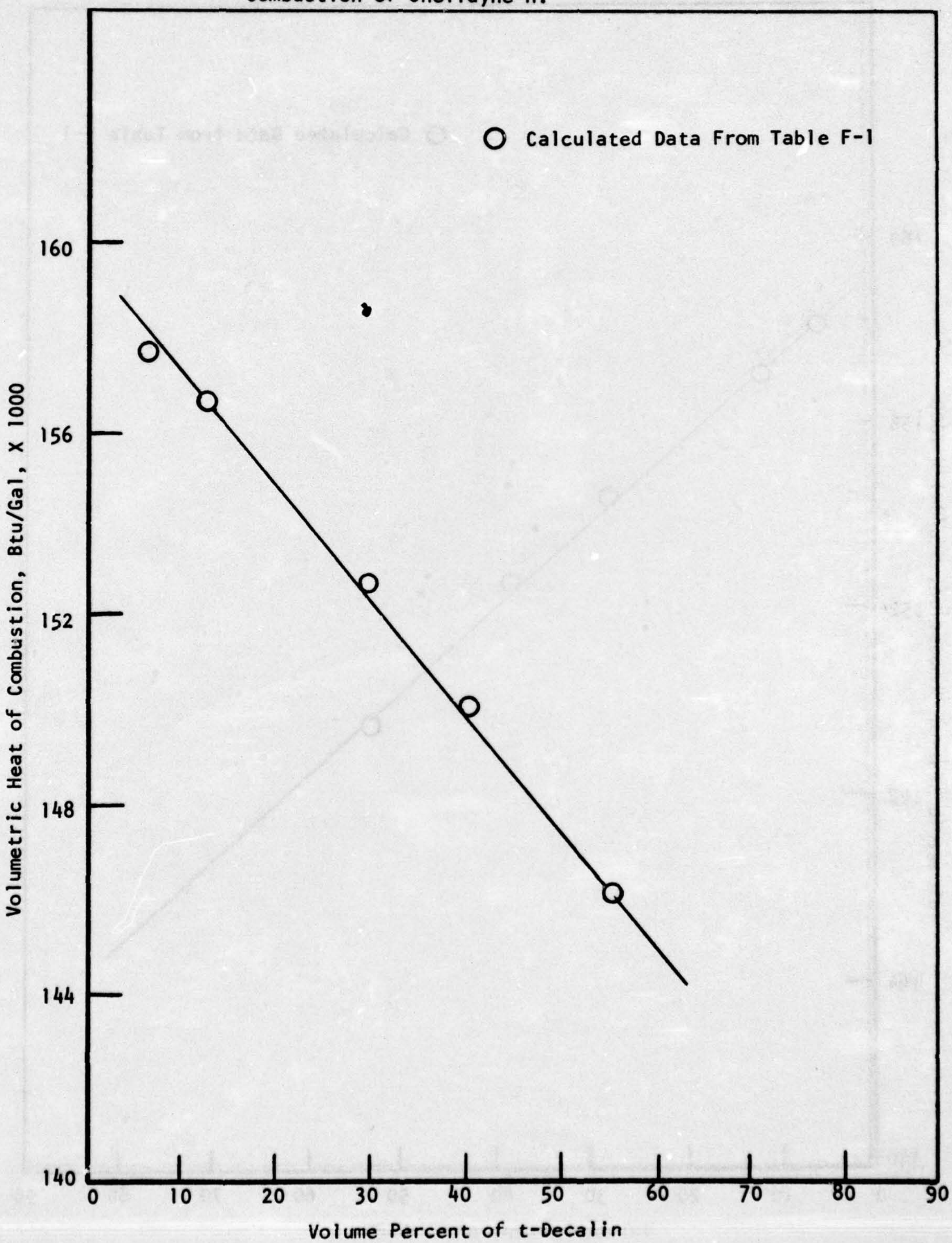


FIGURE F-13. The Effect of TH-MCPD Dilution on the Volumetric Heat of Combustion of Shelldyne-H

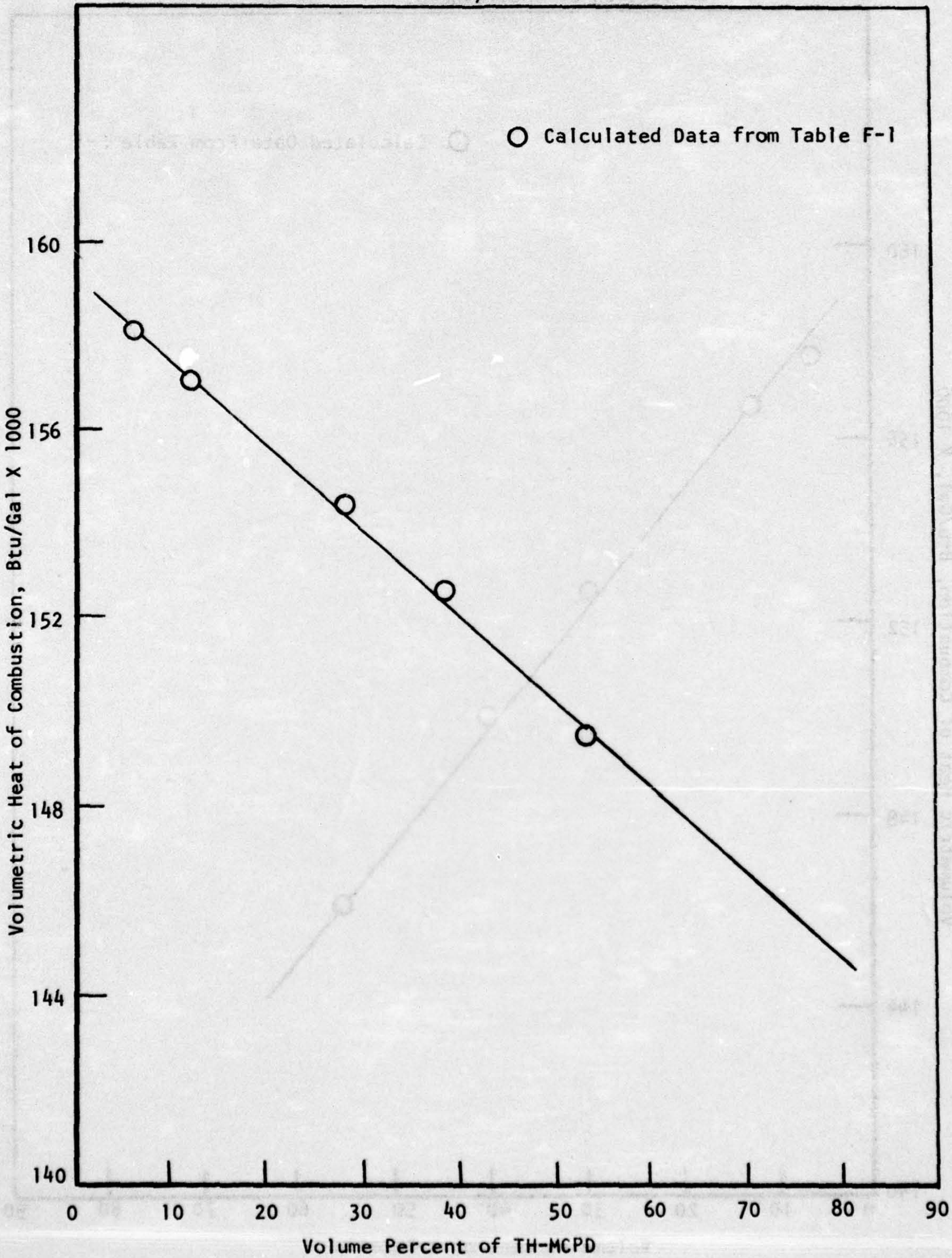
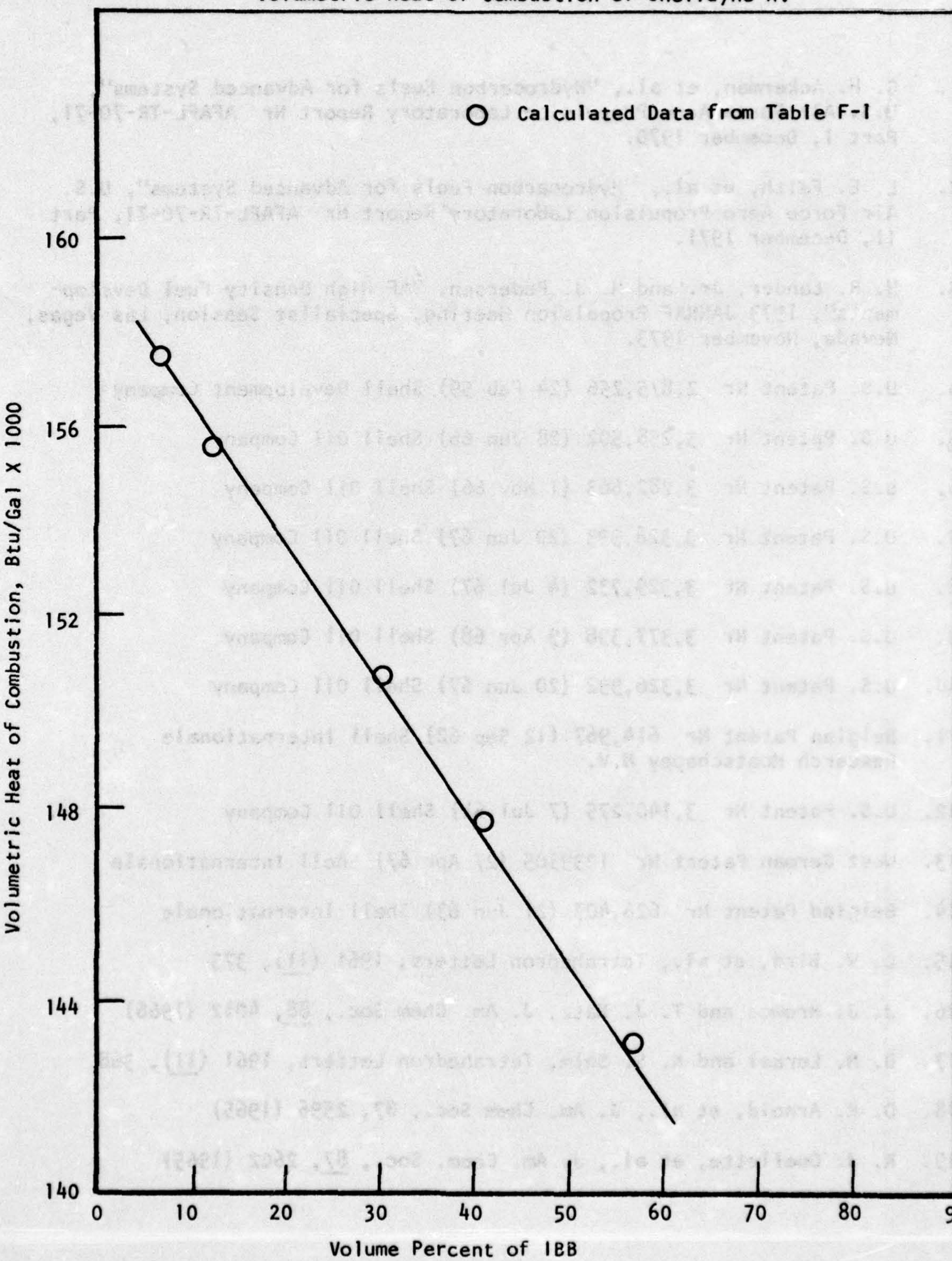


FIGURE F-14. The Effect of Iso-Butylbenzene Dilution on the Volumetric Heat of Combustion of Shelldyne-H.



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